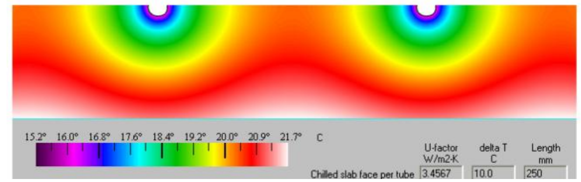
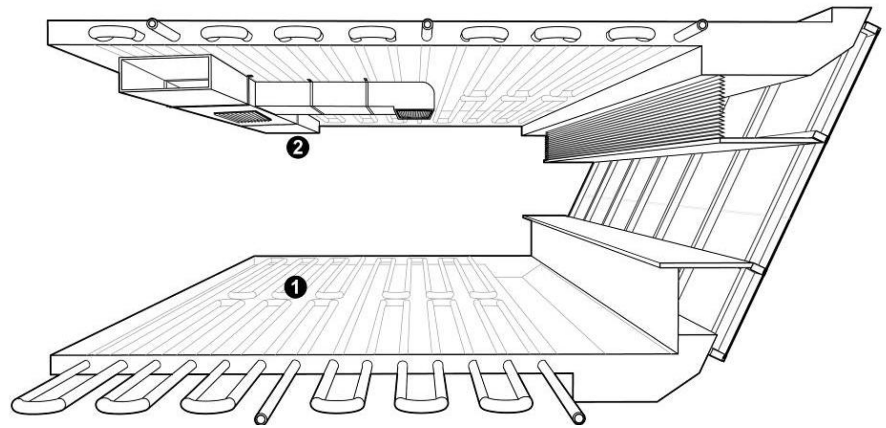
Case Studies for Radiant Cooling in Hot & Humid Climate





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Singapore | Malaysia | China

DOWNLOAD presentation:
http://ien.com.my/downloads/ACAT-IEN.pdf

Two Case Study Office Buildings in Malaysia

“Energy Efficient Buildings”
Malaysian stamp series

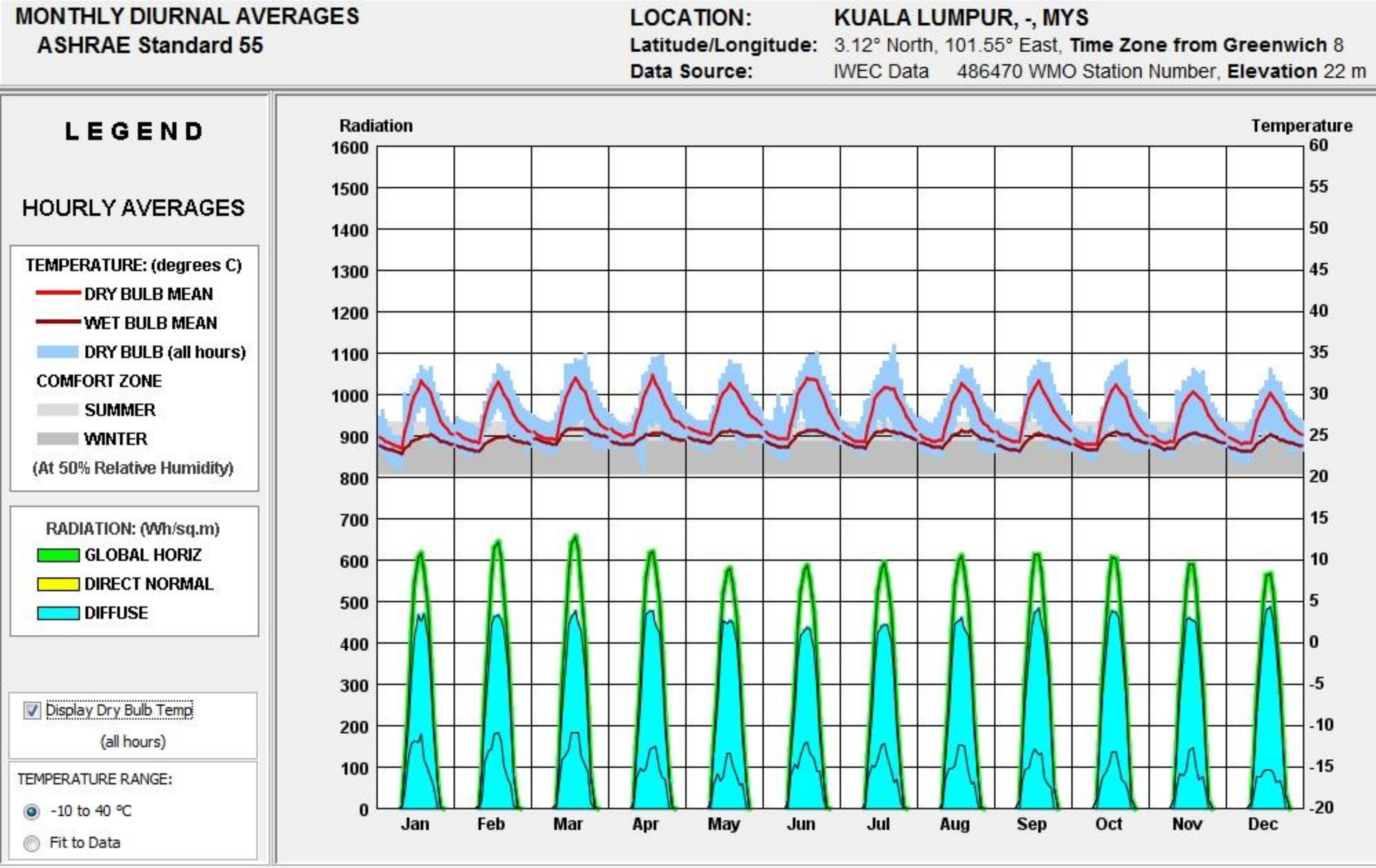
All buildings by IEN Consultants

GEO building

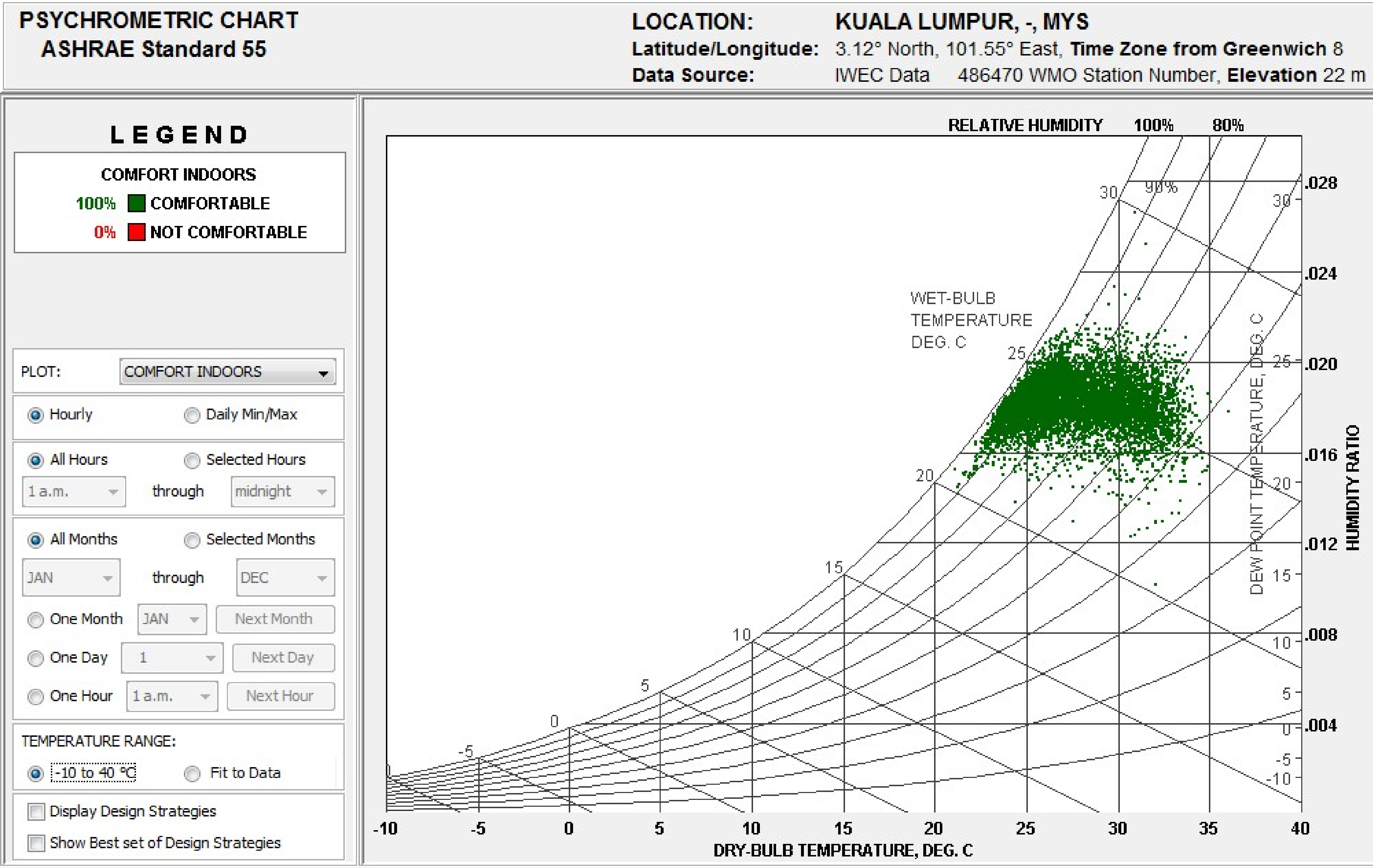
DIAMOND building

Where?
Both located about 25 km south of the capital, Kuala Lumpur, in Bangi and Putrajaya, respectively

Climate Data of Malaysia: Hot & Humid



Climate Data of Malaysia: Psychometric Cart



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What are the Climatic Design Issues?

Climatic parameter	In a cold/temperate climate	In a tropical climate
Sun	Our friend	Our enemy
Wind	Our enemy	Our friend
Daylight	Our friend	Our enemy (perceived to be hot, glary and give unwanted solar tan)

EXAMPLE: Air movement

- less than 0.15 m/s (cold climate)
- higher than 0.15 m/s (tropic climate)
  - *- Recommended range: 0.15 – 0.50 m/s*
  - *- Do not exceed: 0.70 m/s*

EXAMPLE: Sun light / Daylight

Cold climate
"Solar canopy" advertisement

Tropic climate
Skin whitening advert.

Office case study in Bangi, Malaysia:

GEO BUILDING

GEO Building (formerly ZEO) in Malaysia

Key data:

- Gross Floor Area: 4,000 m²
- Energy Index: 64 kWh/m²/year (excl. PV)
- Energy Index: 30 kWh/m²/year (incl. PV)
- Additional construction cost: 18% (excl. PV)
- Additional construction cost: 33% (incl. PV)

EE Features:

- Daylighting (almost 100%)
- EE lighting + task lights
- EE office equipment
- EE server room
- Floor slab cooling
- EE ventilation
- Controls & Sensors
- Double glazing
- Insulation

Greentech Malaysia office, Bangi, Malaysia (Occupation Oct 2007)

Energy Design Concepts

of GEO Building

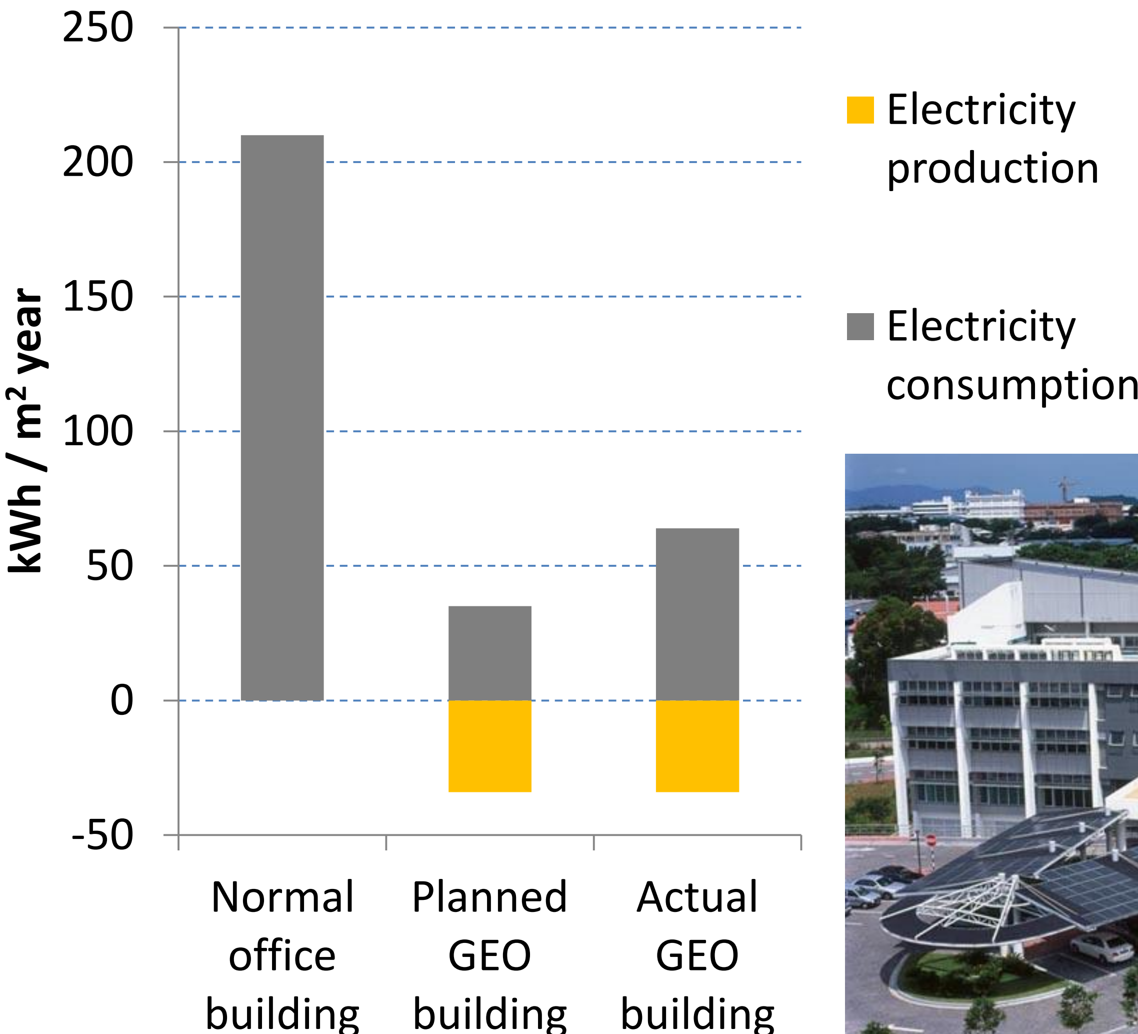
Concept no. 1

Zero Energy Building

Concept no. 2

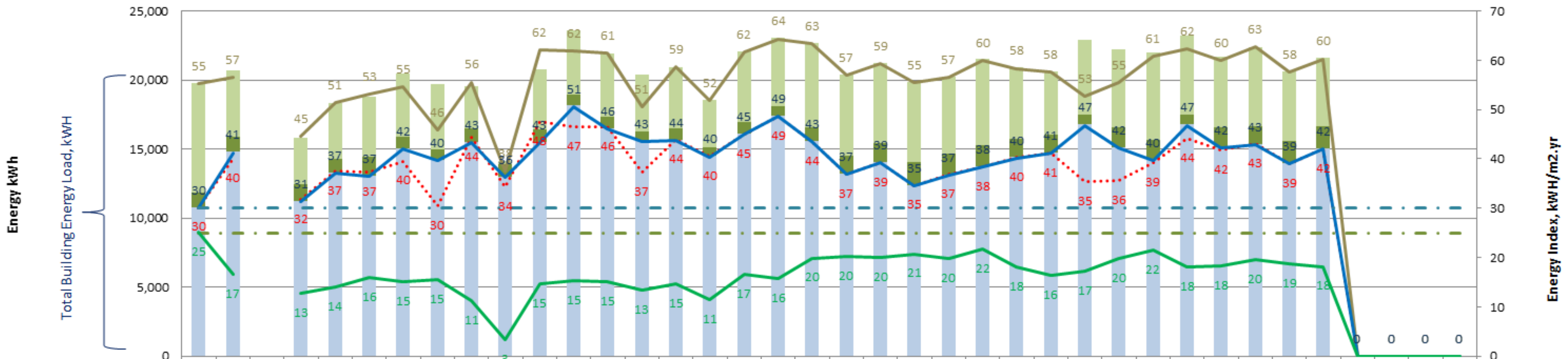
Shift load to the night, hence, reducing peak demand for power utilities

Concept no. 1: Zero Energy Building



GEO building: Latest energy measurements

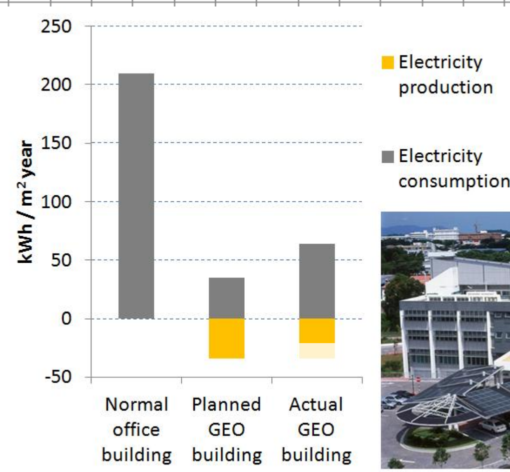
Graph 1 : GEO Building Energy Usage & Generation Performance, 2012-2014(Aug)



	Standard	Average		Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12
kWhPV used	7,949	4,811		3,389	3,994	4,385	4,573	4,752	3,092	250	4,360	4,663	4,564	4,105
kWhRec	1,051	1,114		1,179	1,034	1,319	826	780	945	927	875	816	812	674
kWh Total (net)	10,800	14,788		11,241	13,278	13,098	15,039	14,203	15,541	12,979	15,514	18,145	16,502	15,581
TNB BEI [kWh/m2.yr]	55	57		45	51	53	55	46	56	38	62	62	61	51
TNB NET BEI [kWh/m2.yr]	30	40		32	37	37	40	30	44					
BEMS NET BEI [kWh/m2.yr]	30	41		31	37	37	42	40	43					
Net BEI 30 Line	30	30	30	30	30	30	30	30	30					
PVI 25 Line	25	25	25	25	25	25	25	25	25					
meter PVI [kWh/m2.yr]	25	17		13	14	16	15	15	11					

	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
kWhPV used	4,466	3,412	5,129	4,957	6,106	5,941	5,800	5,753	5,583	6,225	5,153	4,569
kWhRec	807	674	841	677	1,026	1,279	1,336	1,683	1,509	1,528	1,333	1,303
kWh Total (net)	15,682	14,481	16,093	17,396	15,565	13,196	14,063	12,389	13,165	13,745	14,400	14,735
TNB BEI [kWh/m2.yr]	59	52	62	64	63	57	59	55	57	60	58	58
TNB NET BEI [kWh/m2.yr]												
BEMS NET BEI [kWh/m2.yr]												
Net BEI 30 Line												
PVI 25 Line												
meter PVI [kWh/m2.yr]												

	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
kWhPV used	5,437	5,640	6,303	5,741	5,091	5,703	5,024	4,973	0	0	0	0
kWhRec	726	1,472	1,432	726	1,472	1,328	1,657	1,546				
kWh Total (net)	16,777	15,124	14,248	16,777	15,124	15,341	13,952	15,068	0	0	0	0
TNB BEI [kWh/m2.yr]	53	55	61	62	60	63	58	60	0	0	0	0
TNB NET BEI [kWh/m2.yr]		36	39	44	42	43	39	42	0	0	0	0
BEMS NET BEI [kWh/m2.yr]		42	40	47	42	43	39	42	0	0	0	0
Net BEI 30 Line		30	30	30	30	30	30	30	30	30	30	30
PVI 25 Line		25	25	25	25	25	25	25	25	25	25	25
meter PVI [kWh/m2.yr]		20	22	18	18	20	19	18	0	0	0	0



2014 (Aug)

40% drop
(inverter problem)

No change

Concept no. 2: Shift load to the night

Electricity demand curve

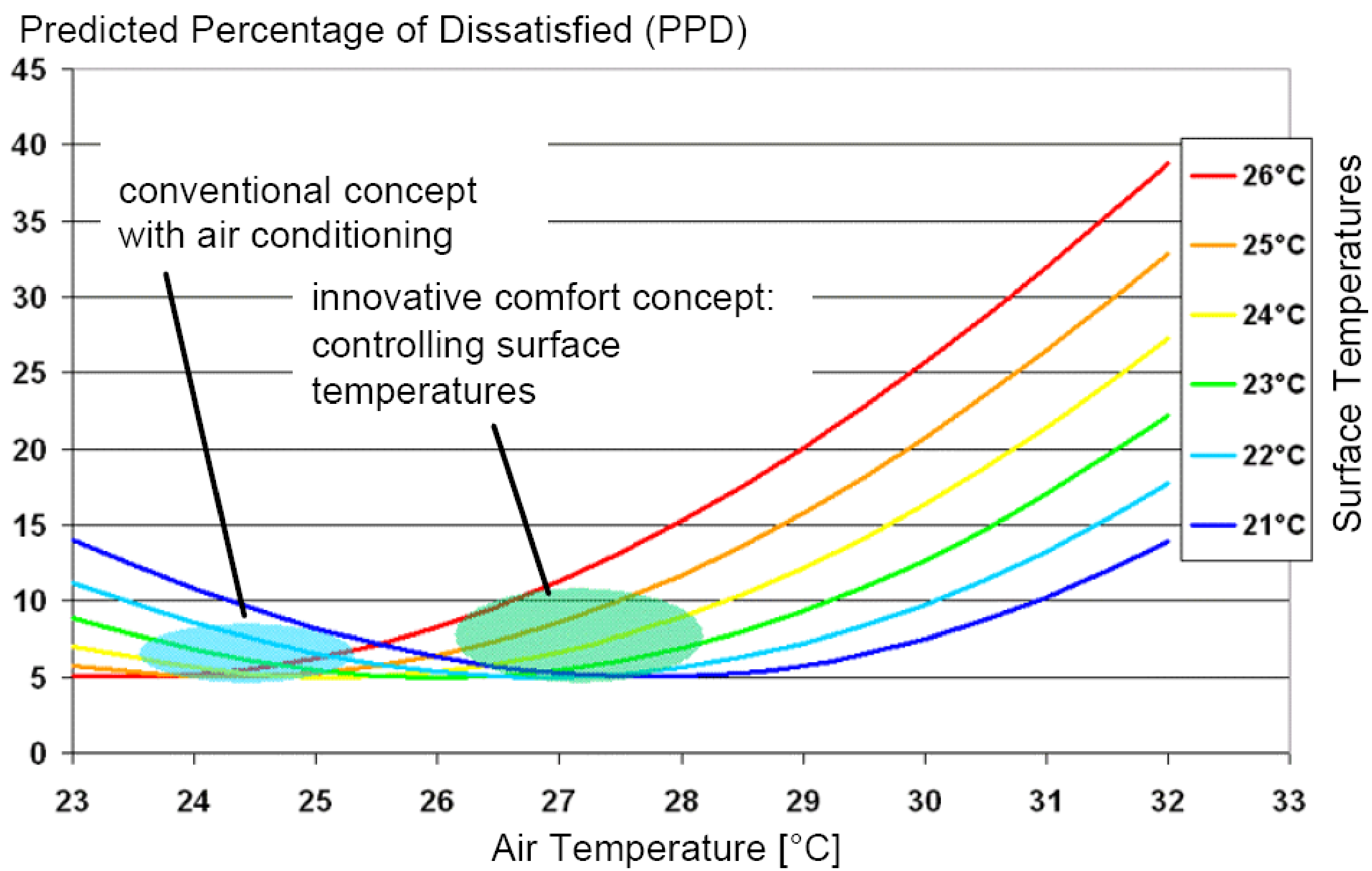
Malaysia (2012)

	BUY electricity from the grid	**SELL** electricity to the grid
How?	Thermal storage	Solar PV

Building integrated photovoltaic (91 kW_p)

Floor slab cooling (18°C) and Phase Change Material tank (10°C)

Radiant Cooling allows Higher Air Temperature



Predicted percentage of dissatisfied (PPD) according to Prof. O. Fanger
different surface temperatures; no direct radiation
office work, light clothing air velocity 0.15 m/s; humidity 11 g/kg

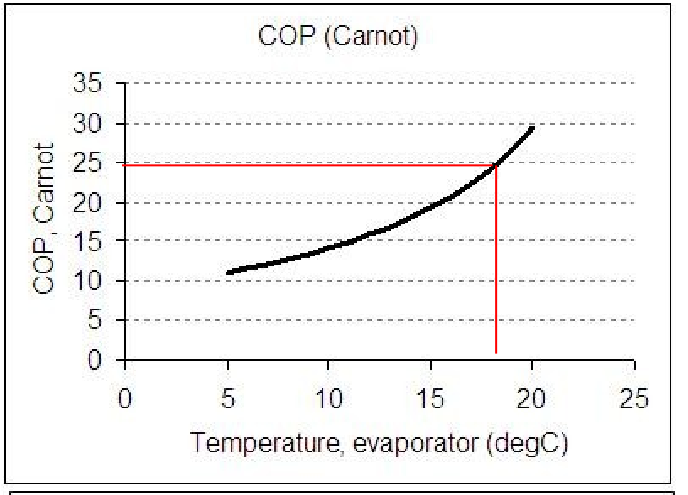
Efficient High Temperature Cooling

$$COP_{refrigerator} = \frac{T_c}{T_H - T_C}$$

- 2 Chillers:
  a) High Temperature cooling (18°C) for Floor Slab Cooling system **(very high COP possible)**
  b) Conventional chiller (7°C) for fresh supply

- Chiller Operation Primarily at Night (lower temperature at condensing side → **higher COP**)

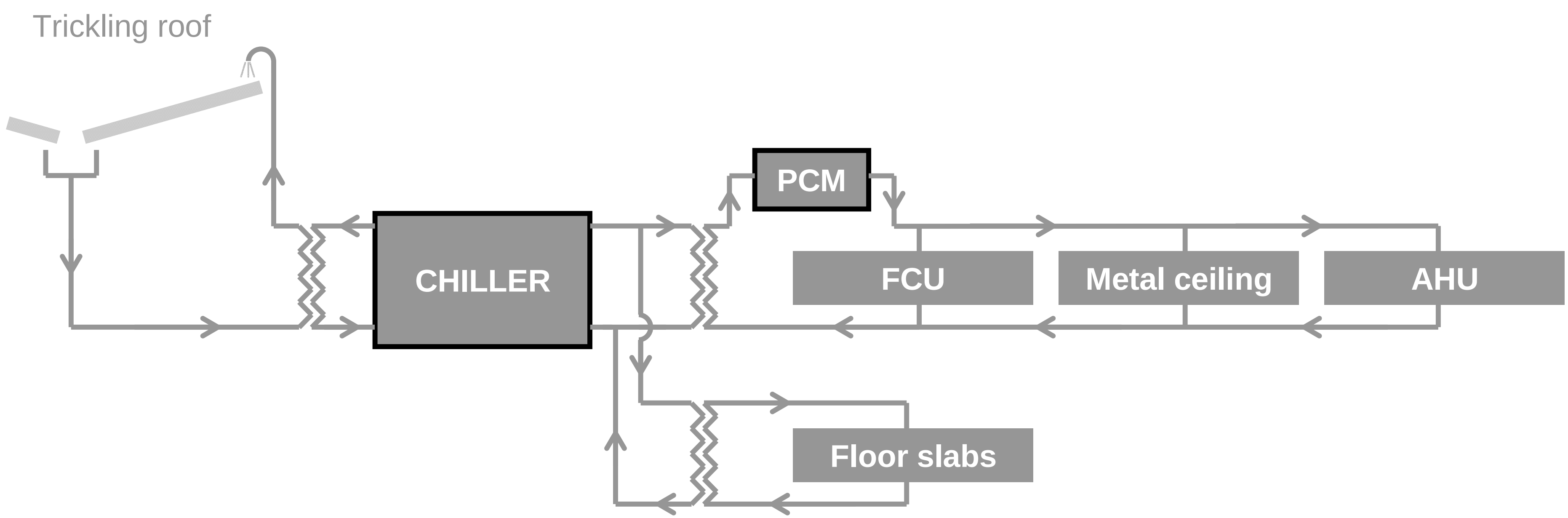
- Chillers only supply cooling to thermal storages, hence, **maximum COP** for chiller operation can be ensured at all times. NB. Maximum COP is at part load (~75% load)



The COP increases with increasing temperature of the evaporator, for example for high temperature cooling at 18°C instead of at the conventional 7°C. Here, the theoretical maximum COP (Carnot) is shown for a constant condenser temperature of 30°C

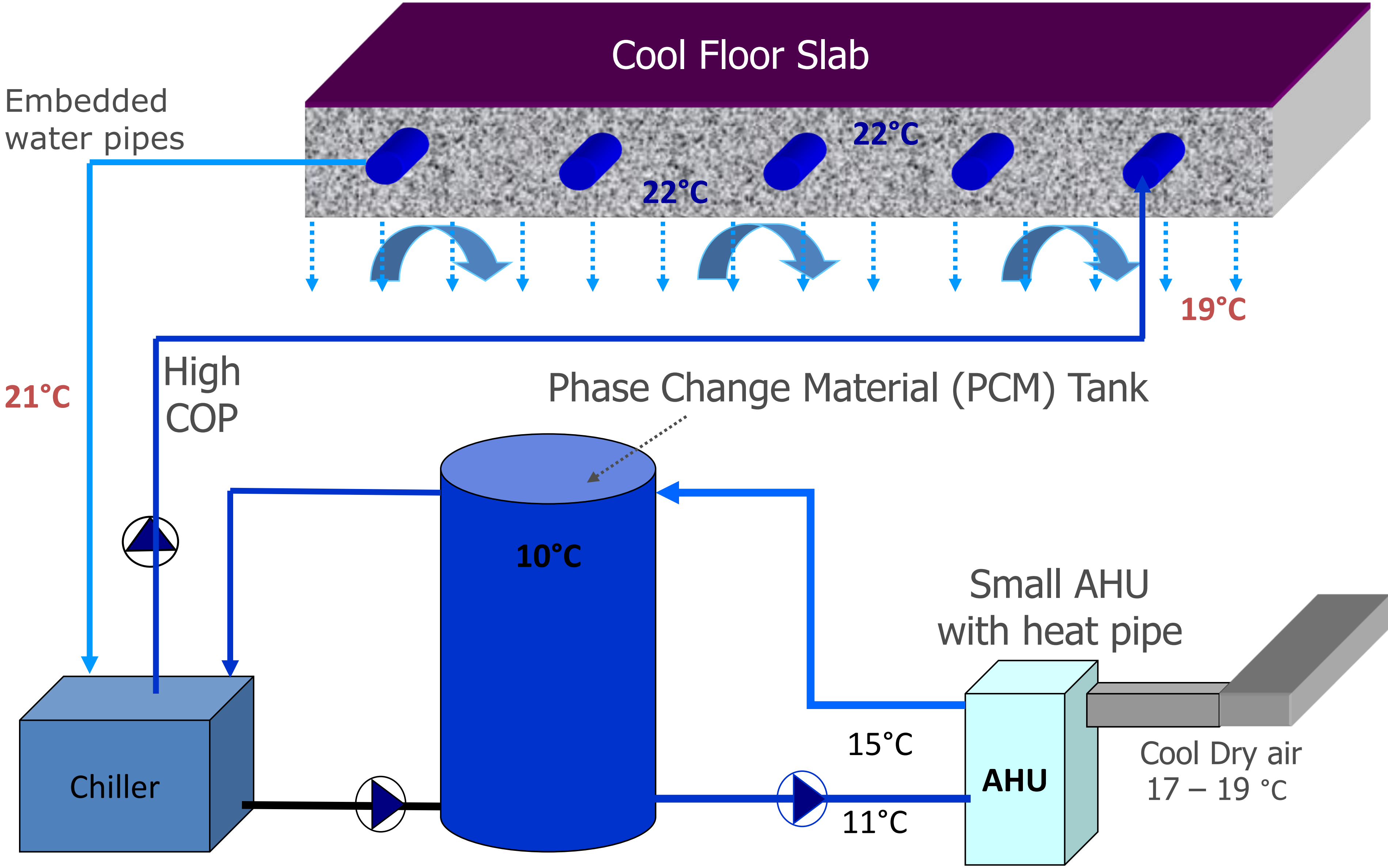
Schematic Design of Cooling System

GEO building



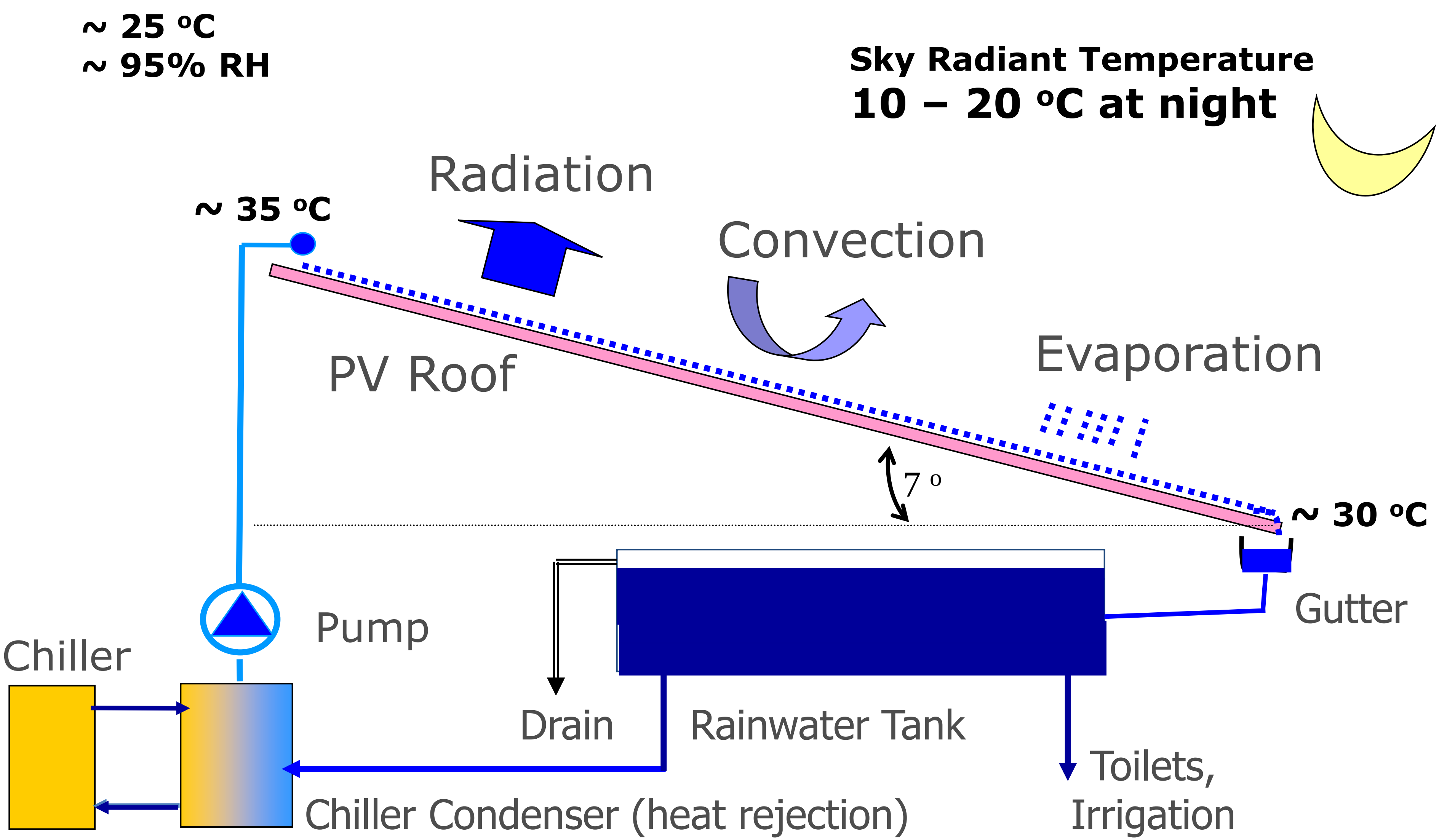
PCM:	Phase Change Material (thermal storage tank with “10°C ice”)
FCU:	Fan Coil Units
Metal ceiling:	Radiant cooling metal ceiling
AHU:	Air handling unit
Floor slabs:	Concrete floor and ceiling slab cooling (TABS, thermally activate building structure)
Trickling roof:	7° tilt flat roof flooded with condenser water at night to eject heat (replaces cooling tower)

Cooling Storage in Floor Slabs and PCM Tank



Rainwater Collection and River Roof

(alternate cooling tower)



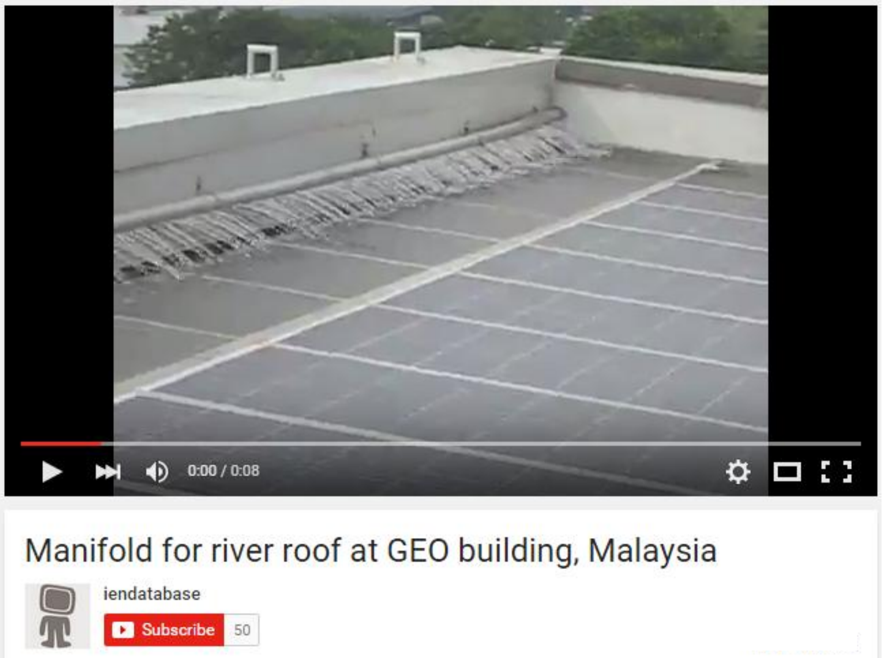
The River Roof of GEO Building

to be operated at night only

Video 1:
Gutter for ‘cooling tower’ water & rainwater

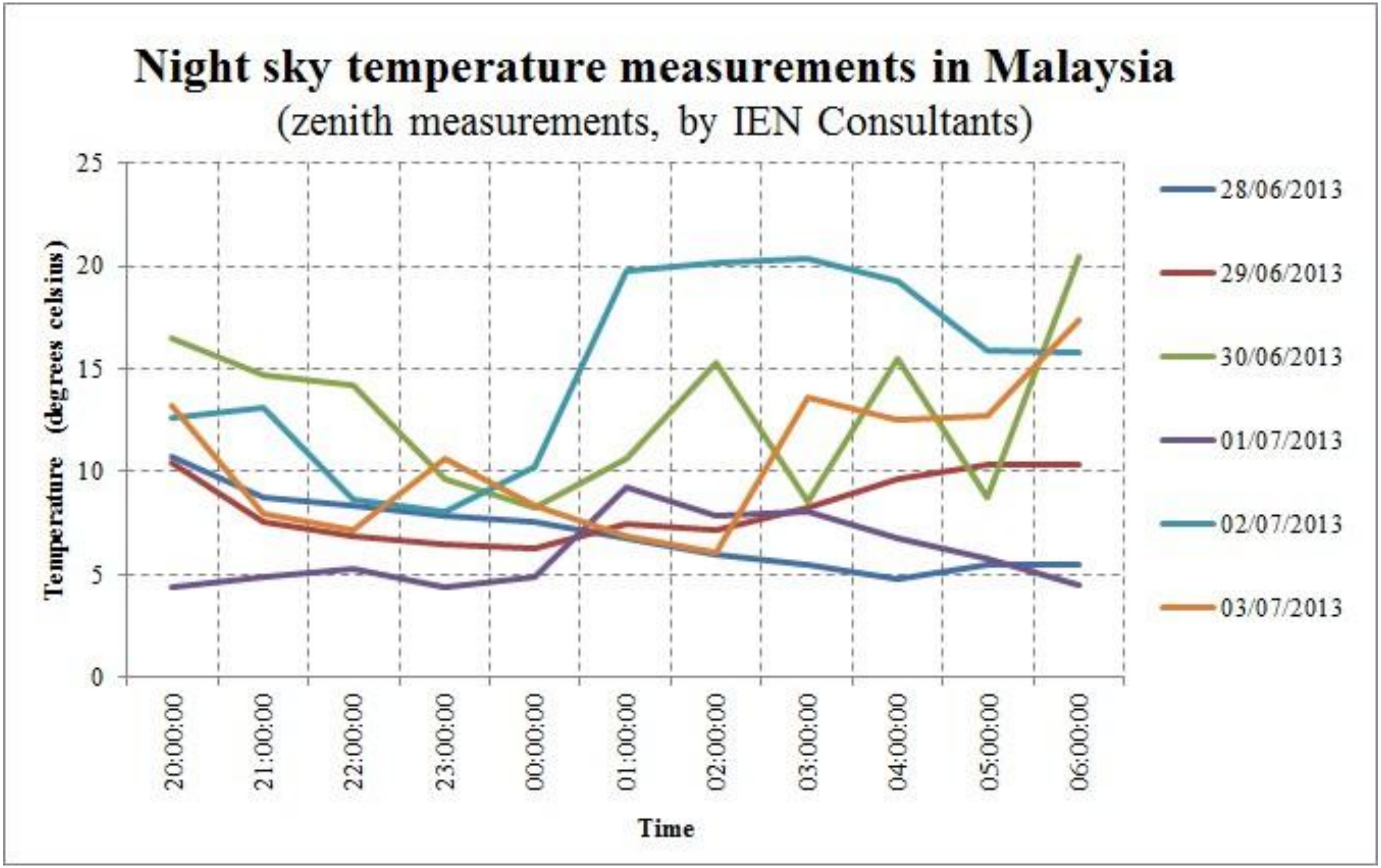
Video link:
https://www.youtube.com/watch?v=h8gC4dlB330

Video 2:
Manifold splashing water onto PV roof



Video link:
https://www.youtube.com/watch?v=nb_JntSXoiA

River roof cooling primarily through sky radiation



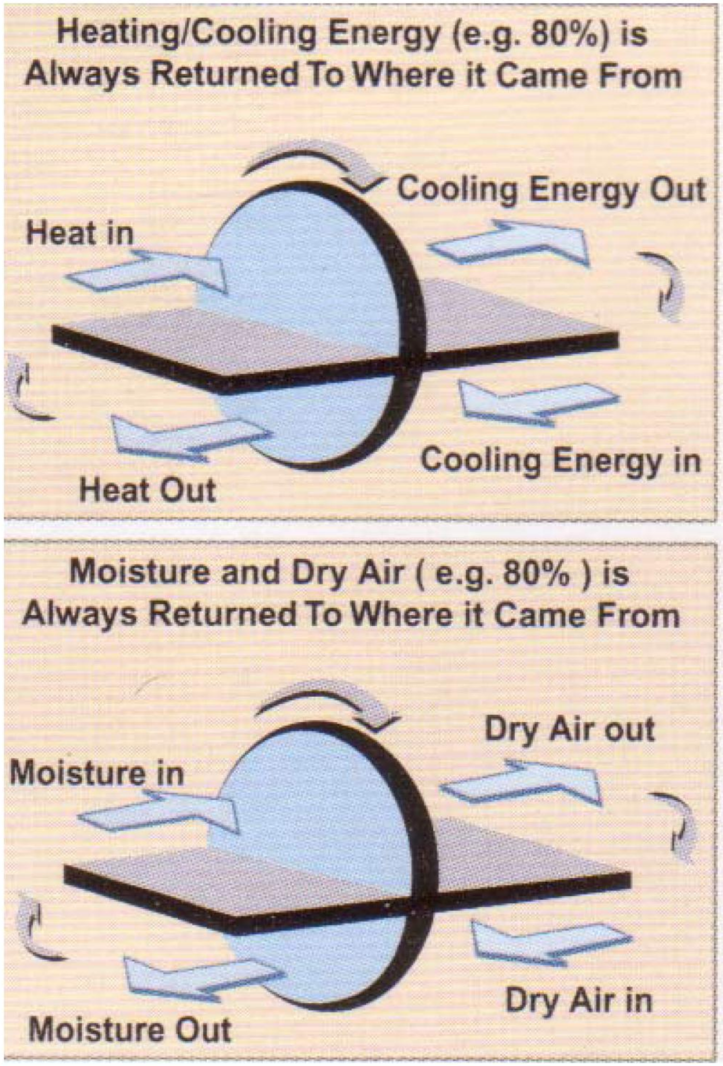
Phase Change Material Tank

- Melting point: 10°C
- Total storage capacity: 580 kWh
- Charged with 7°C water (night time)
- Used for dehumidification of air: 19 → 8 g/kg

Dimensions: ~ 3 x 3 x 2.5 meters

Energy Recovery Wheel

Latent and sensible recovery

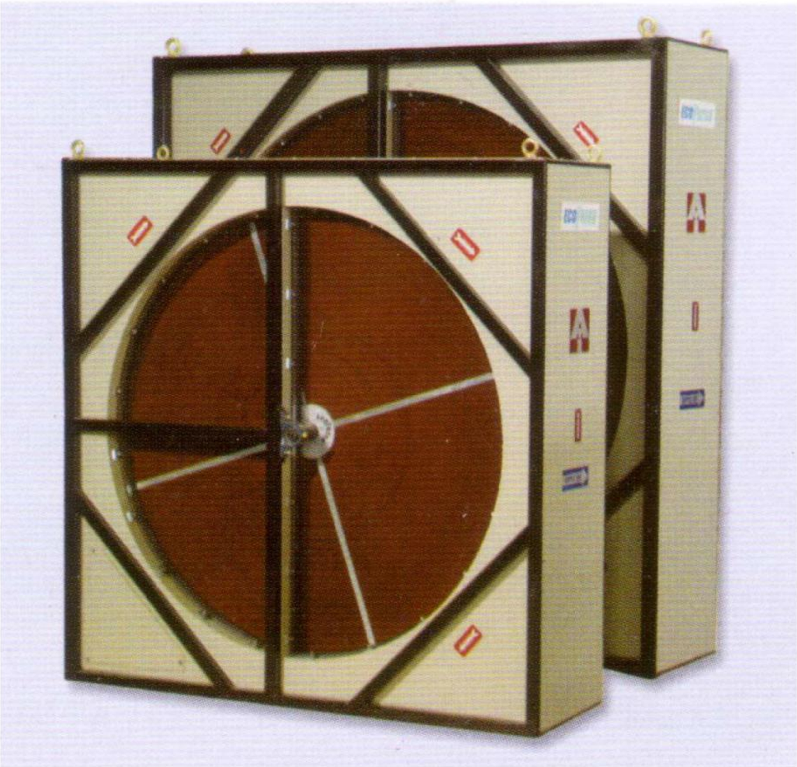


Working principle of energy recovery wheels

Photographed at building during construction

Energy Recovery Wheel

Latent and sensible recovery



EcoFresh Heat Wheels
Bry-Air, My

Energy recovery ventilators:
- desiccant coated heat wheels (molecular sieve coated)
- heat and humidity recovery
- typical efficiency: 50 .. (60 %) .. 79 %

Example for the GEO Building:

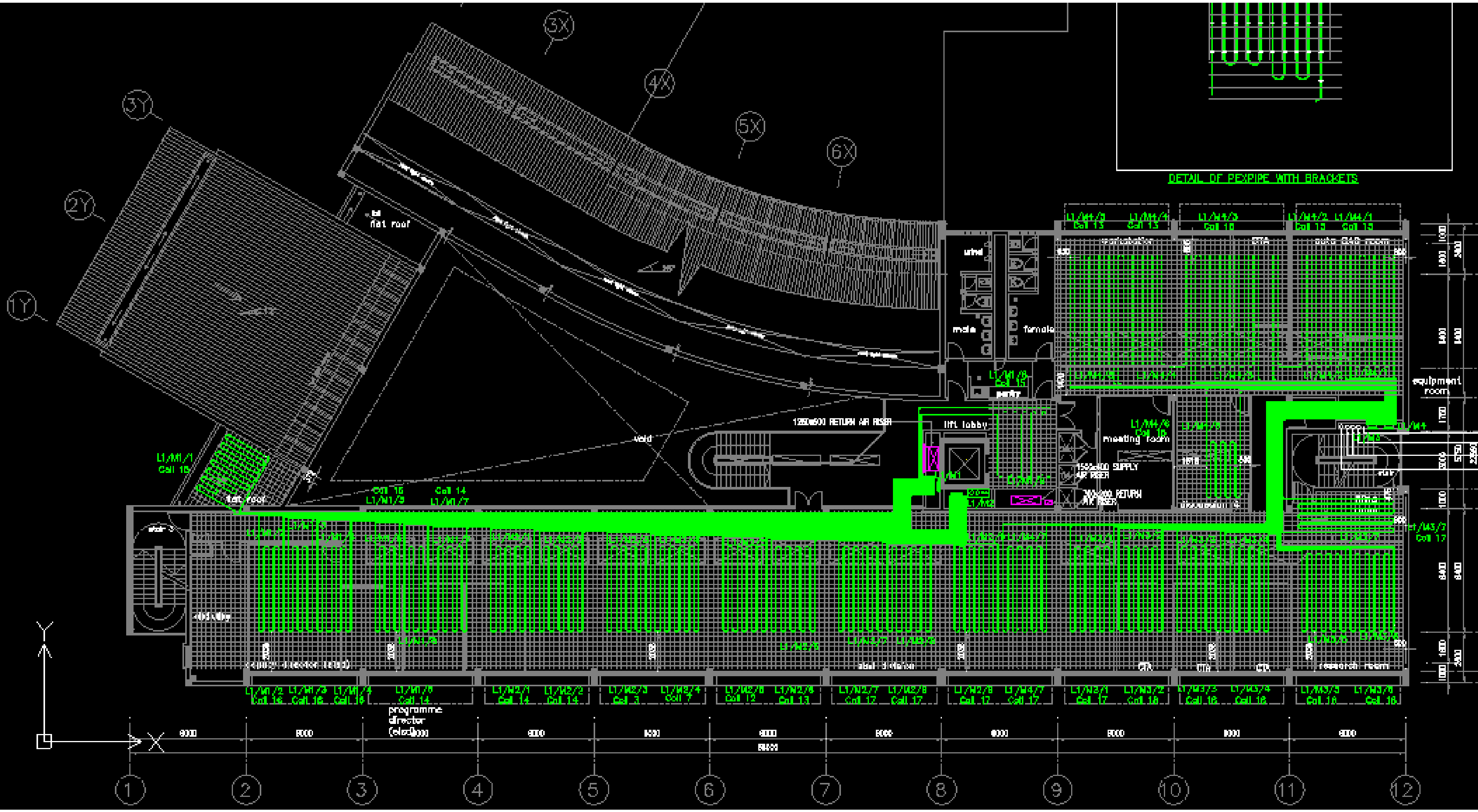
Cooling Capacity	Latent heat recovery
249.2 kWh/m²a	65.6 kWh/m²a
184.4 kW	68.2 kW

savings:
- about 26 % of cooling energy
- about 36 % of cooling capacity

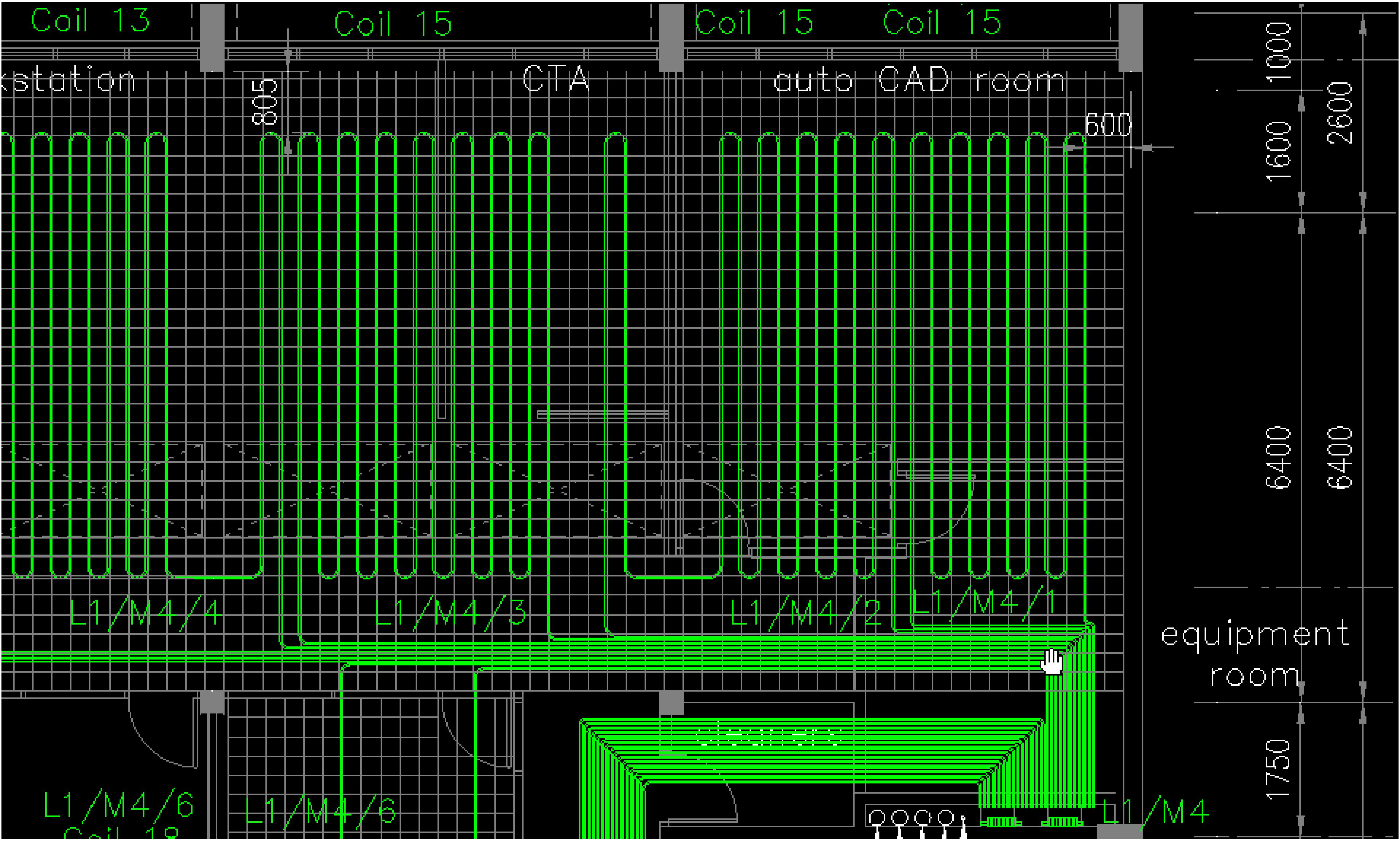
GEO building: Floor Slab Cooling

- PEX pipes
- Embedded in concrete slab
- Supply temperature: 18-20°C
- Return temperature: 22-24°C
- Night time operation only

GEO building: Floor Slab Cooling



GEO building: Floor Slab Cooling



Energy Model for Concrete Floor Slab Cooling

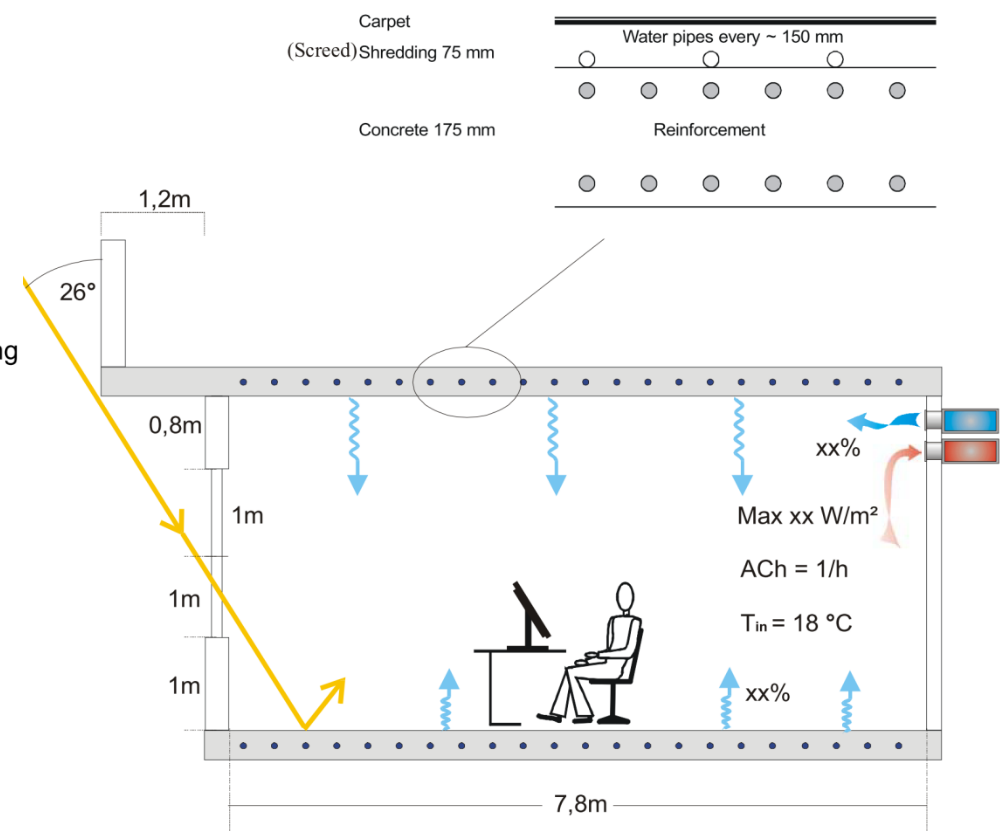
GEO Building

Computer modeling of GEO Building

by Transsolar using TRNSYS

boundary conditions

floor area and volume	95 m² / 356 m³
length facade: depth: height:	12.2 m 7.8 m 3.75 m without suspended ceiling
facade: 50 % opake 50 % glazings with frames	 20 cm leightweight concrete sun protection glazings 50 % light transmission 25 % SHGC Ug-value = 1.1 W/m²/K
shading overhang	1.2 m
Orientation	South
humidity capacity of surface	5 x air humidity capacity



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Energy Model for Concrete Floor Slab Cooling

GEO Building

Computer modeling of GEO Building

by Transsolar using TRNSYS

Occupation

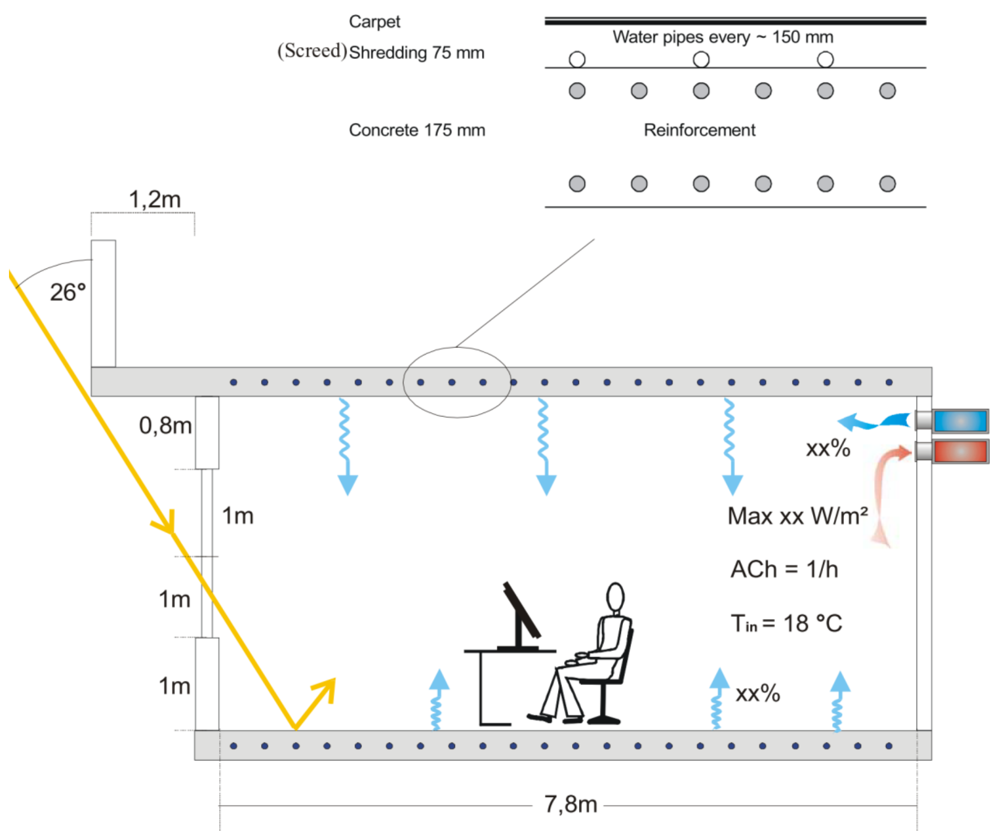
Persons	10 with 75 W sensible heat gain from 8 am to 5 pm
PC	10 with 31 W, variant: 10 with 100 W

Mechanical ventilation

Airchange	1/h starts 2 h before operation time and stops 1 h after operation time
Inlet air temperature	18 °C
Inlet air absolute humidity	8.5 g/kg
recycling air at night	0.1 1/h to keep 75 % relative air humidity

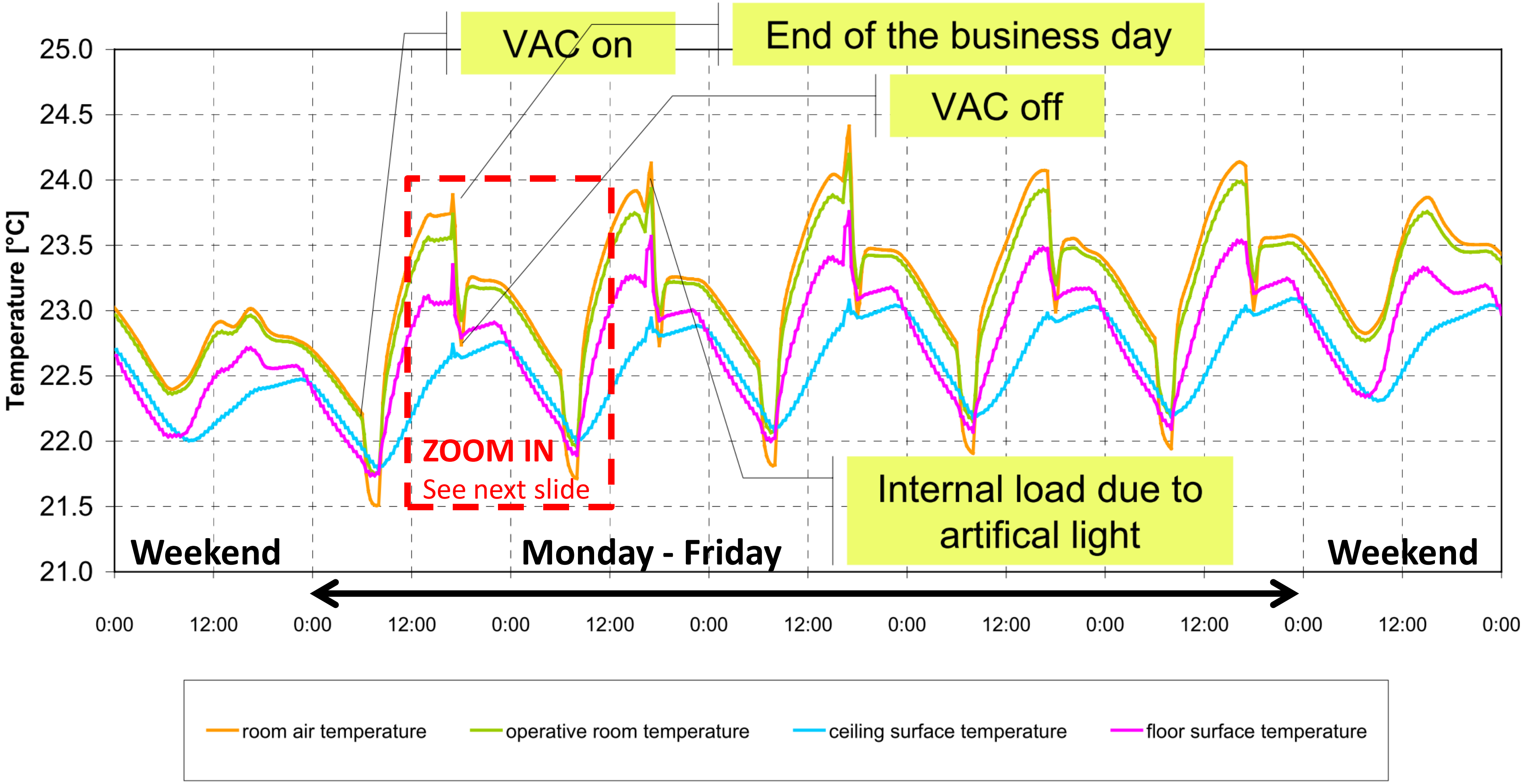
Slab cooling

Operation time	10 pm to 8 am
Inlet fluid temperature	20 °C
Mass flow	12 kg/m²/h
Pipe dimension	20x2 mm, distance: 15 cm
active area	80 %



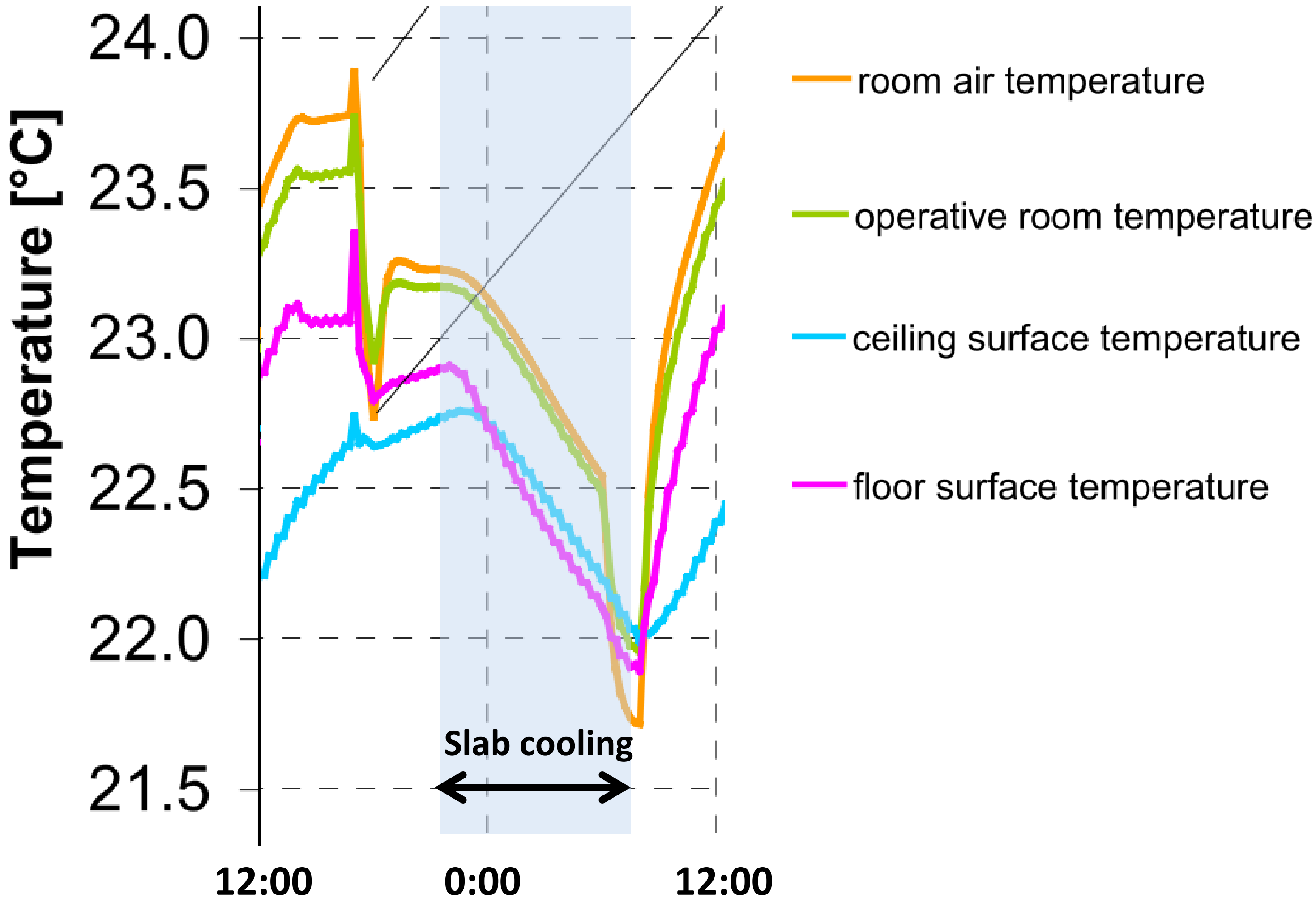
Energy Model for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



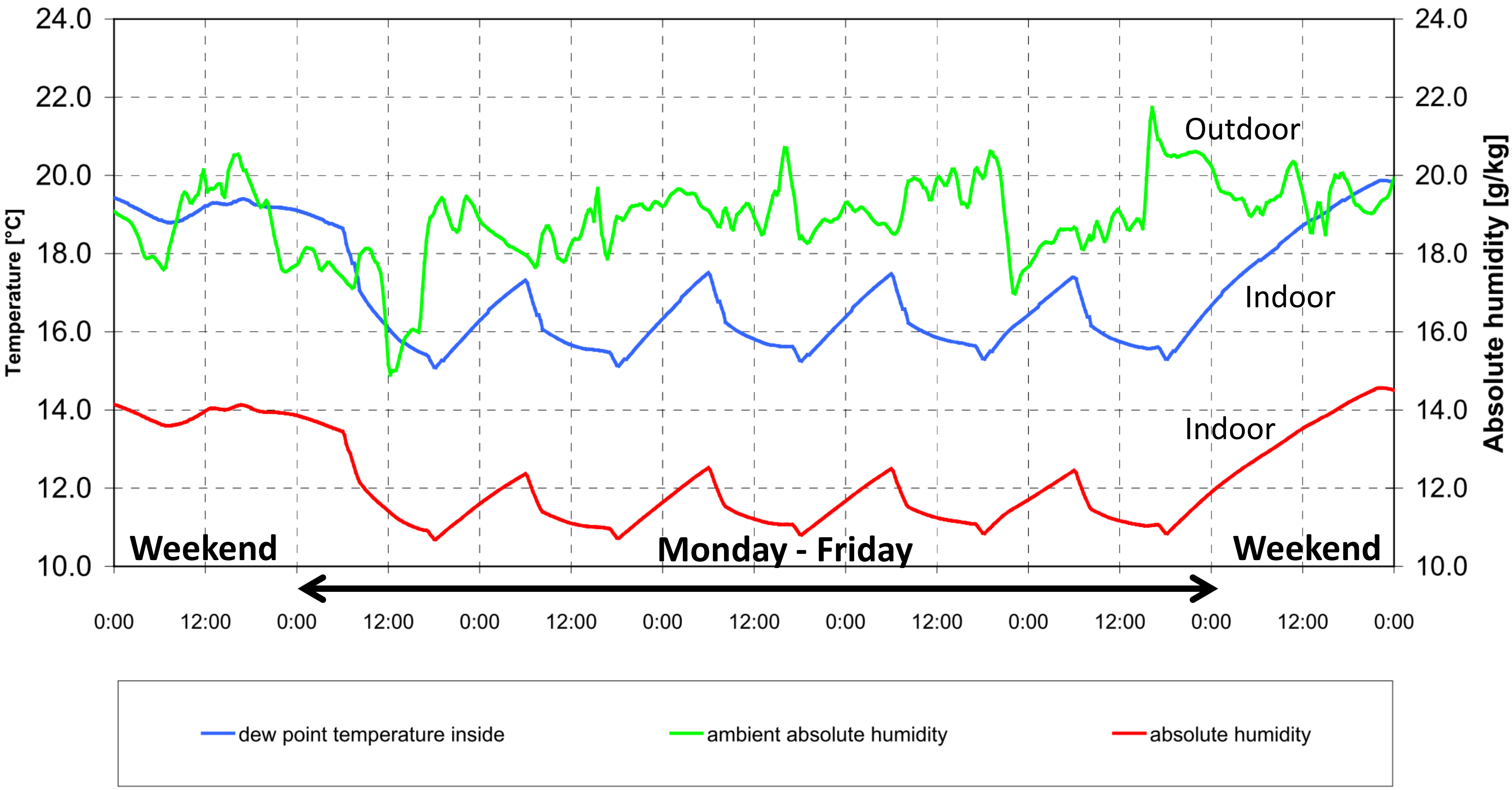
Energy Model for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



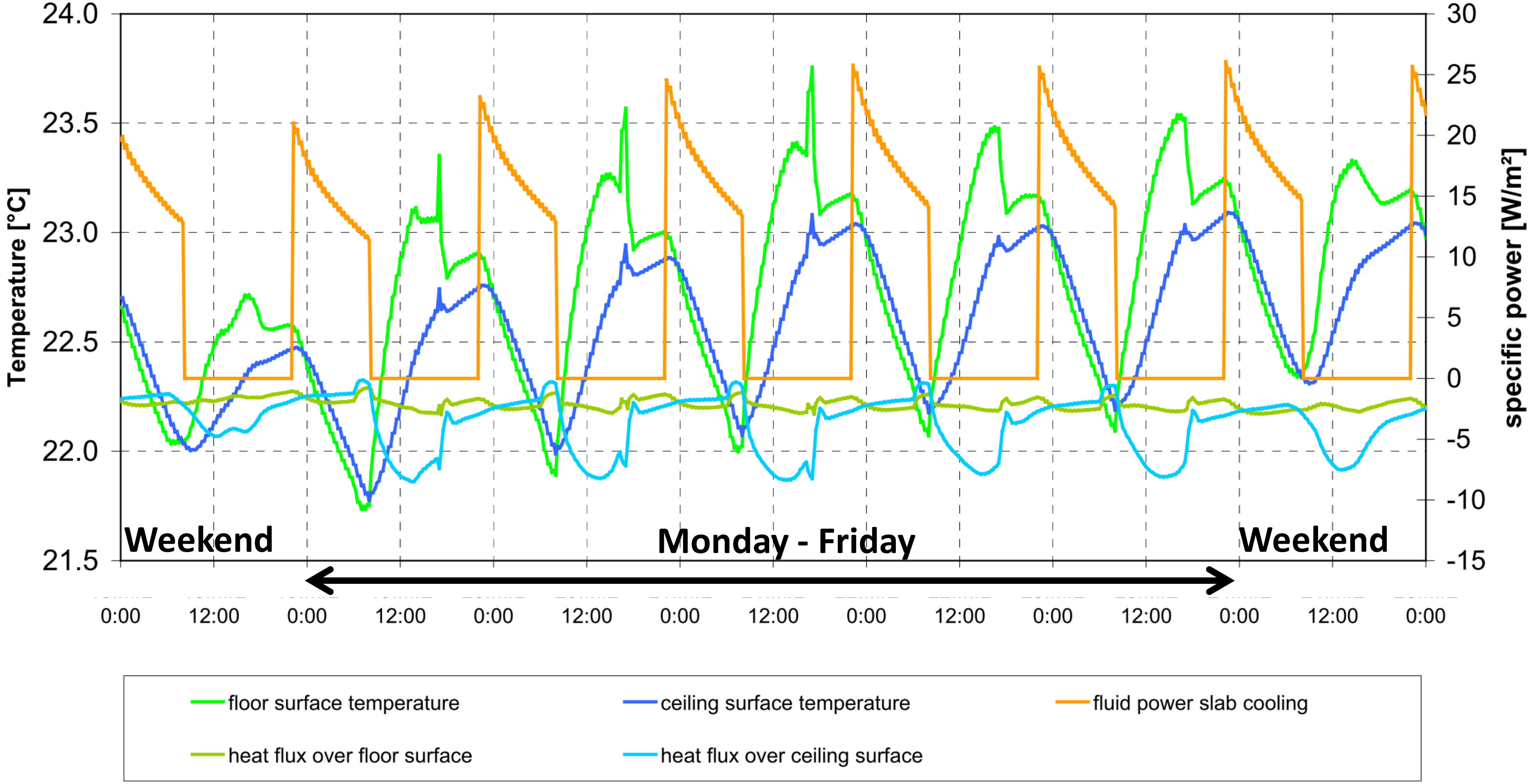
Energy Model for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



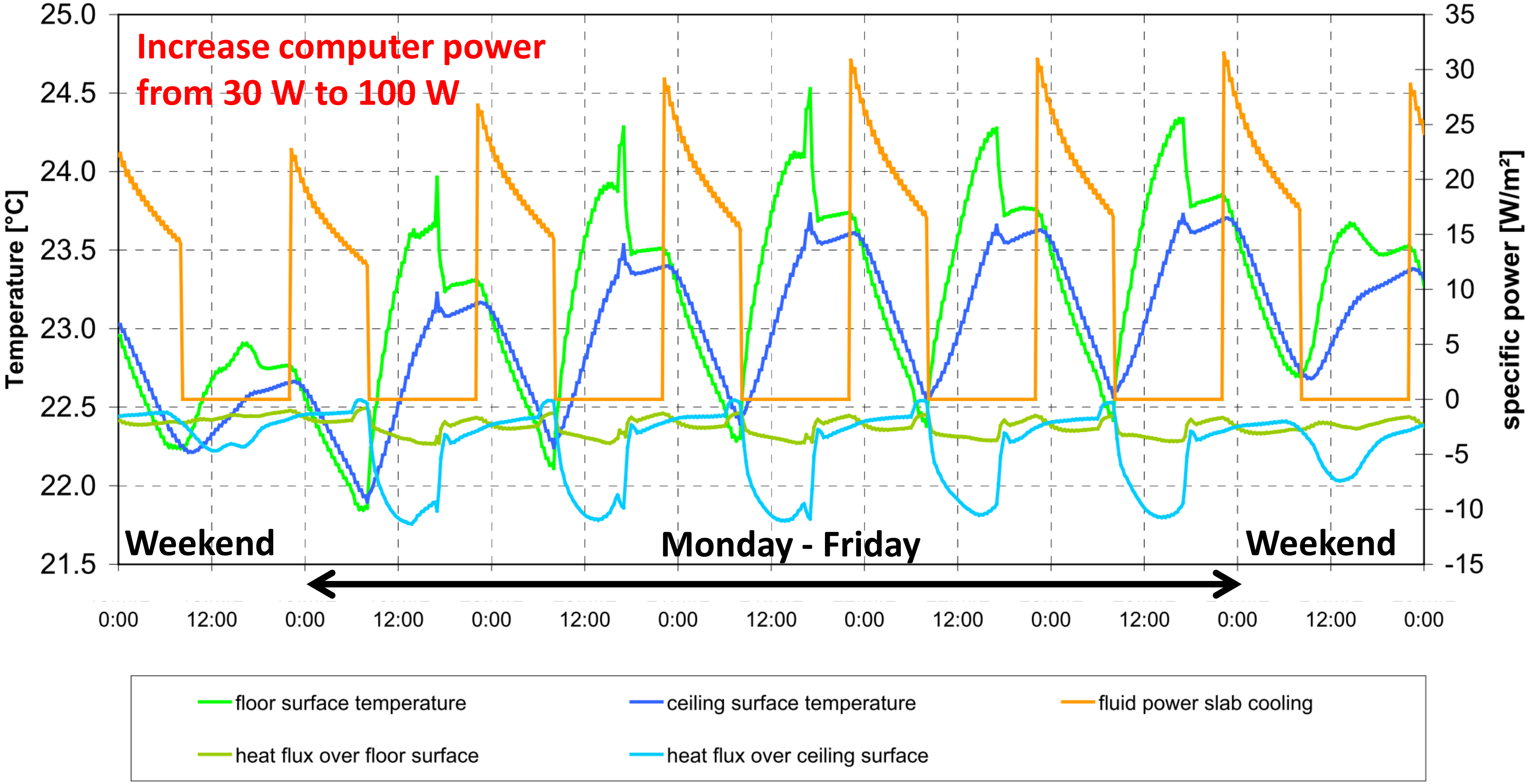
Energy Model for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



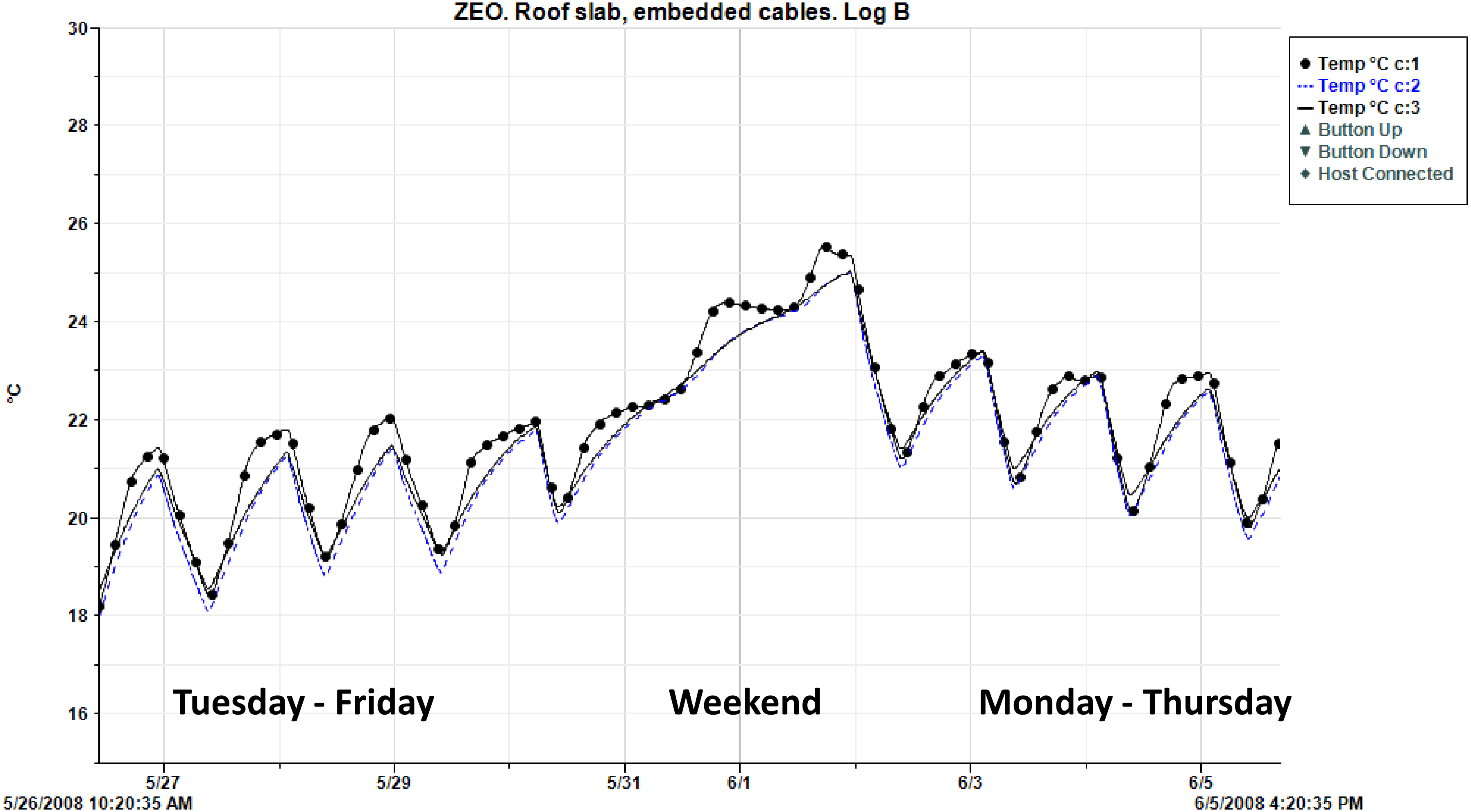
Energy Model for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



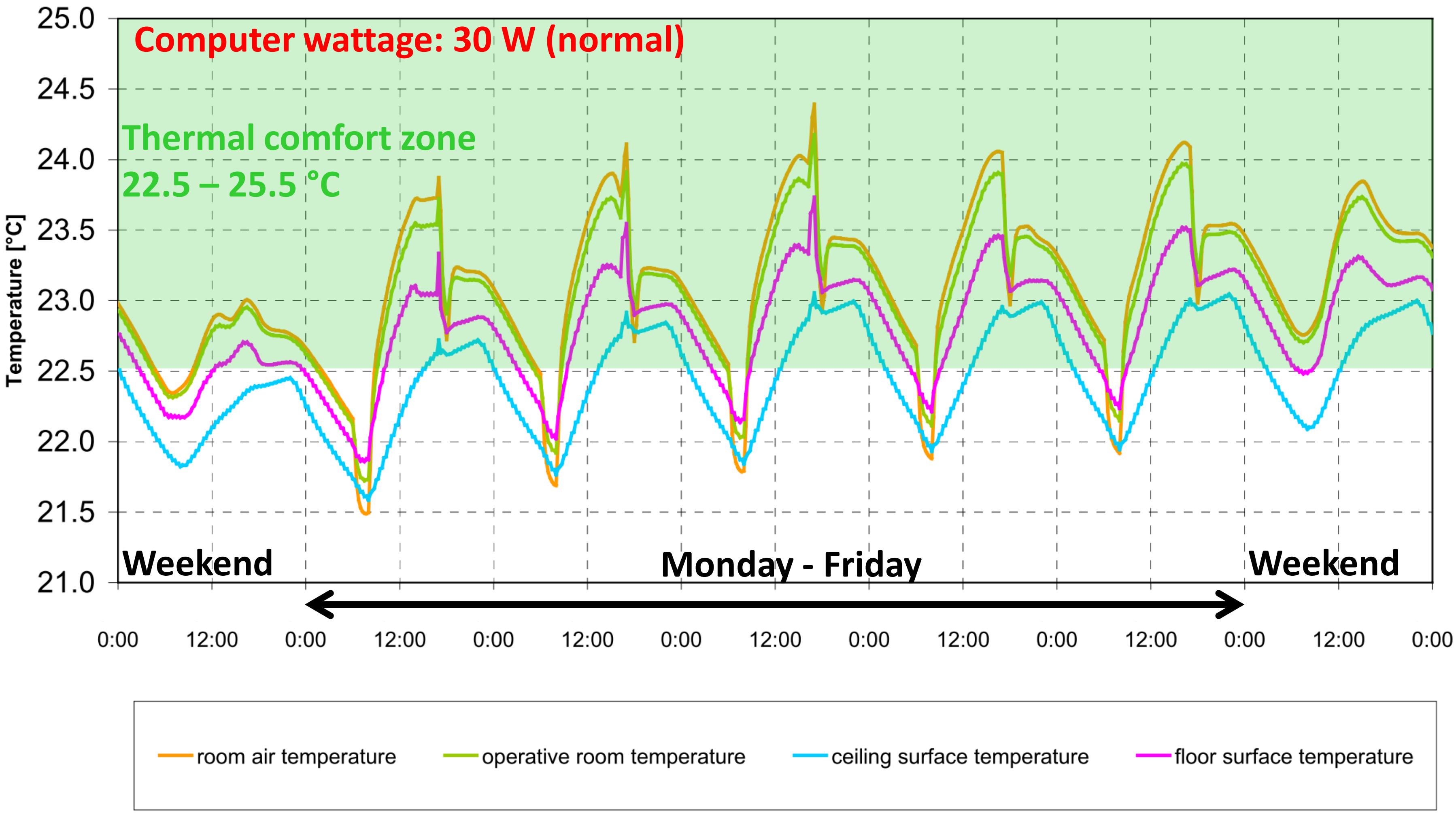
Measured Concrete Slab Core Temperature

Roof slab of GEO Building



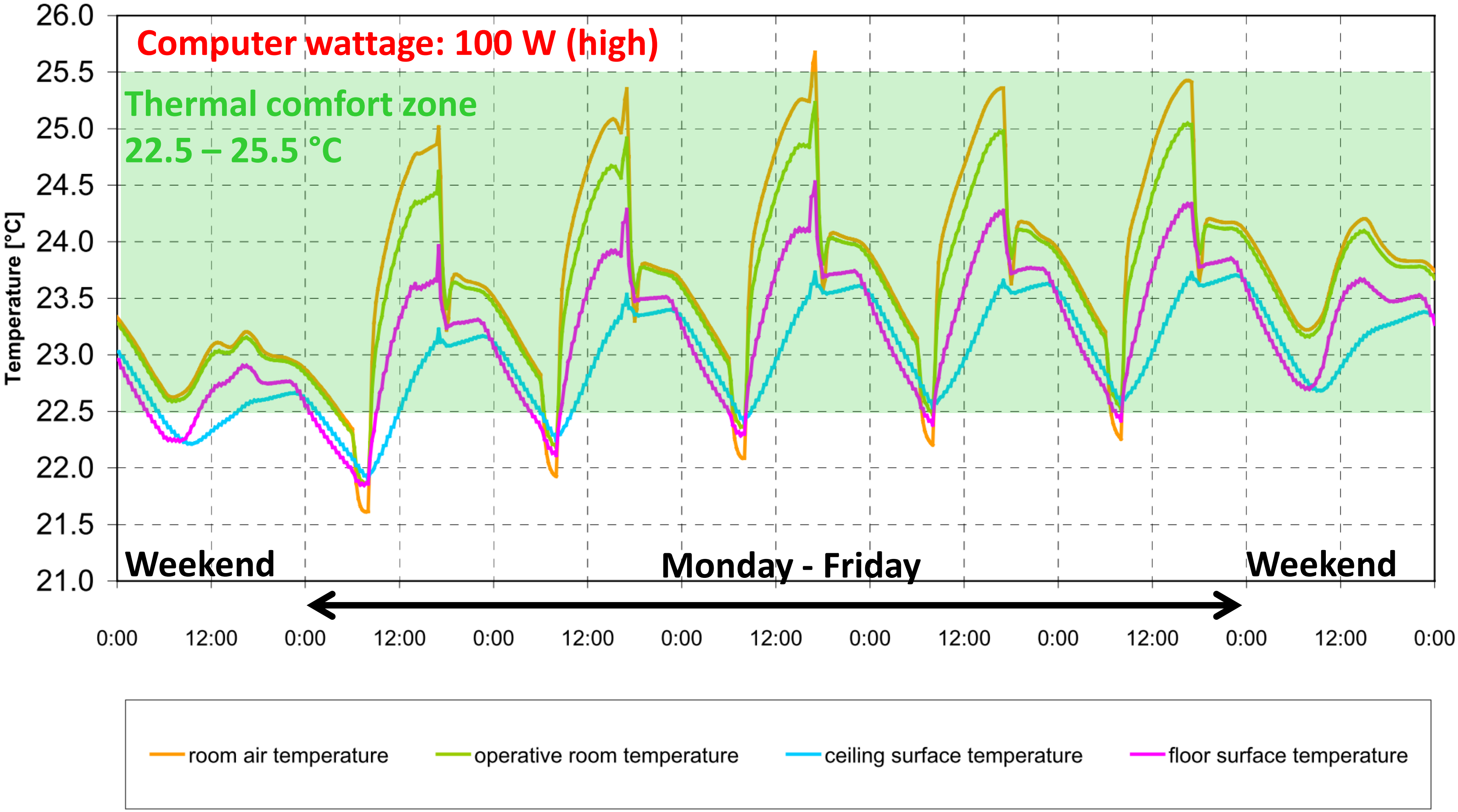
Thermal Comfort for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



Thermal Comfort for Concrete Floor Slab Cooling

Slab cooling 10 pm – 8 am



Measured Temperature for Open Plan Office

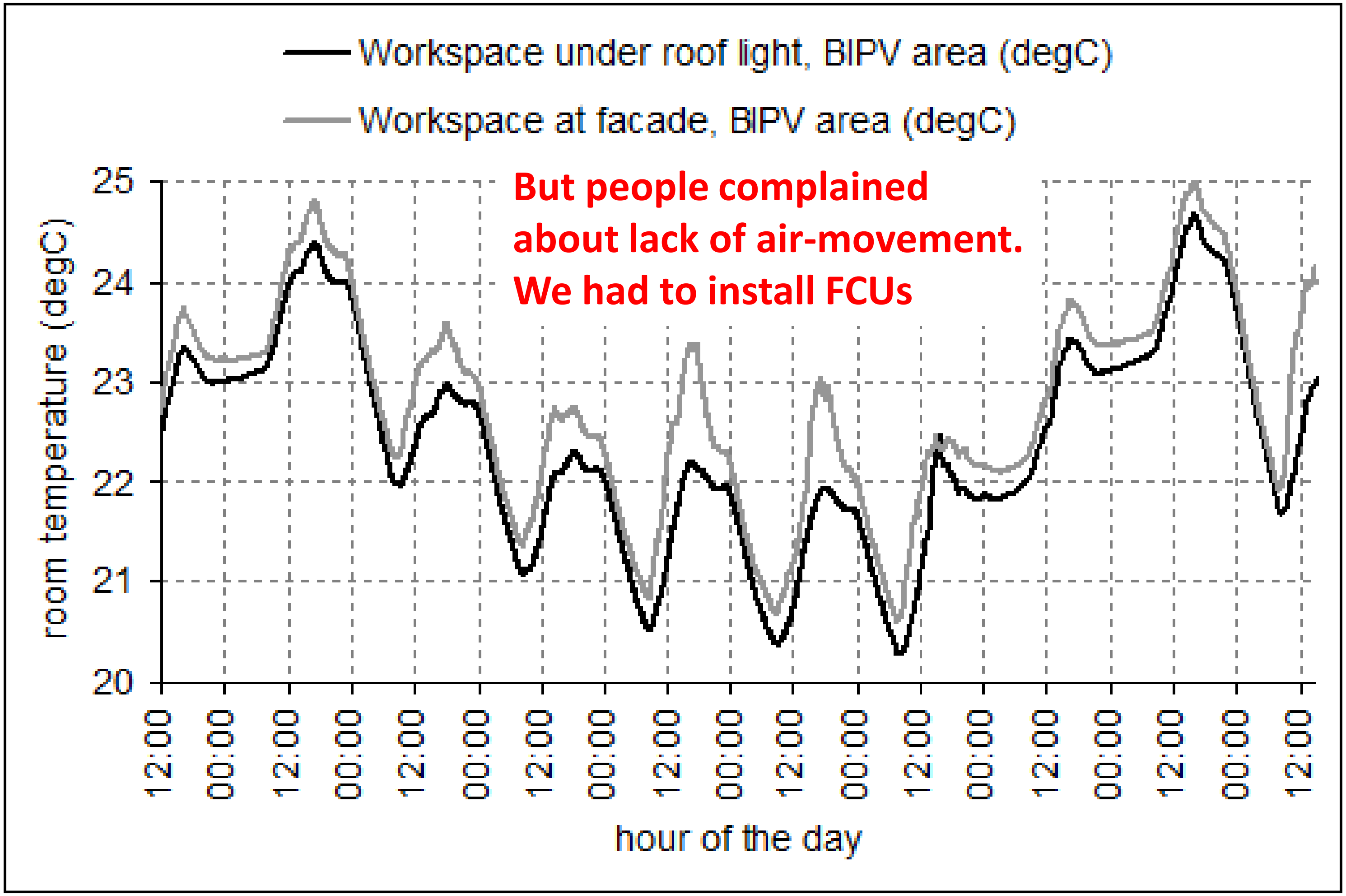


Figure 13: Temperature measured in each workstation from 1 – 10 March 2008

Measured Dew Point Temperature for Open Plan Office

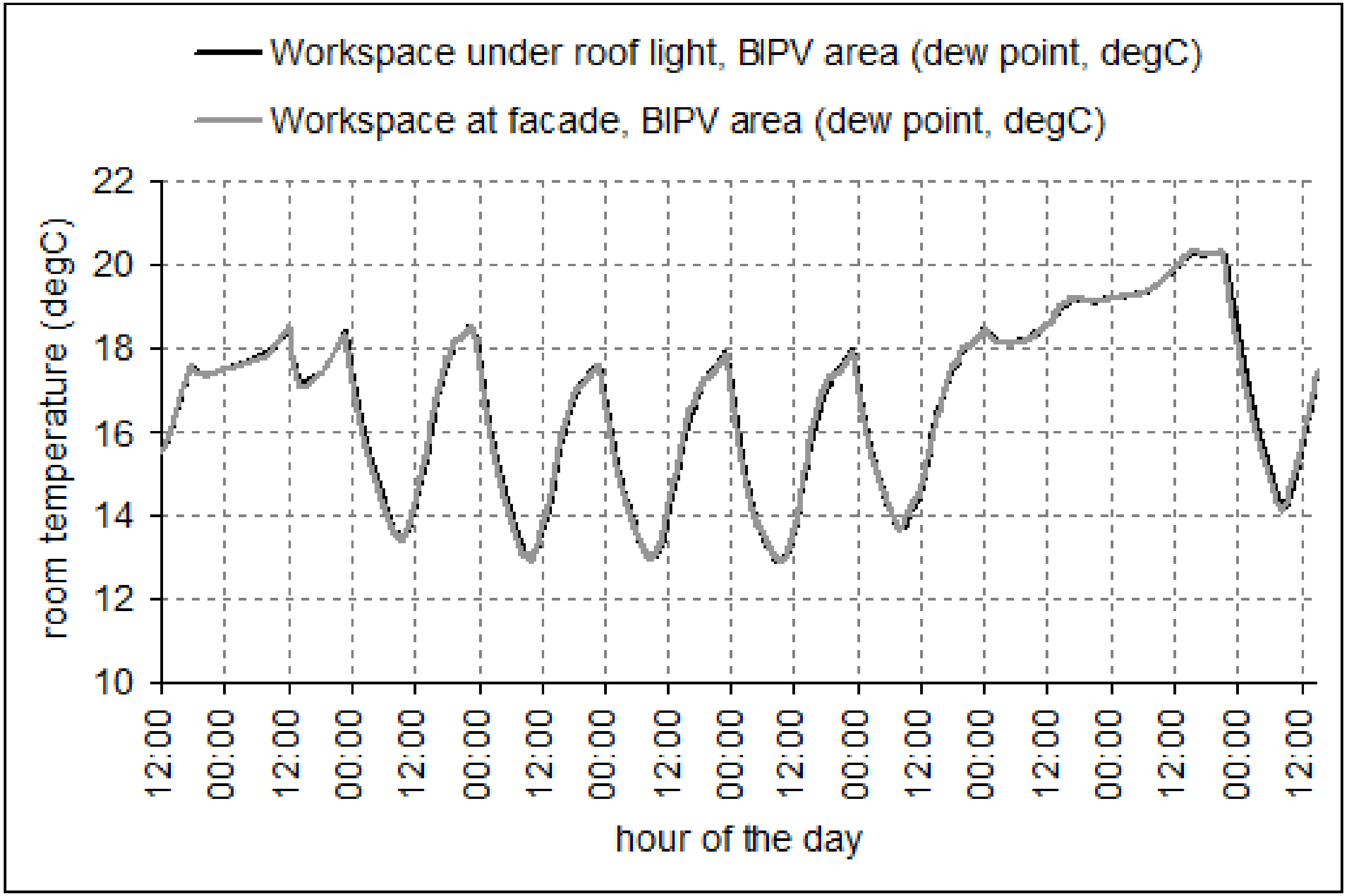
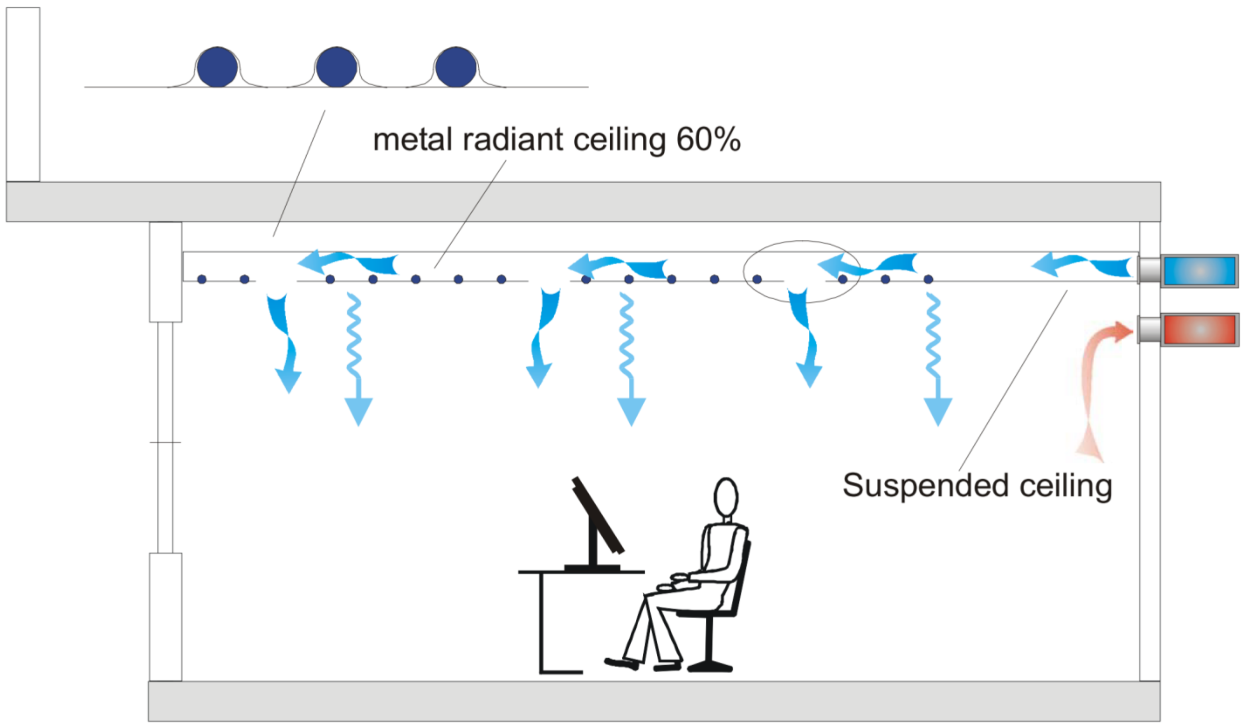


Figure 14: Dew point measured in each work station from 1 – 10 March 2008

Energy Model for Metal Ceiling Cooling

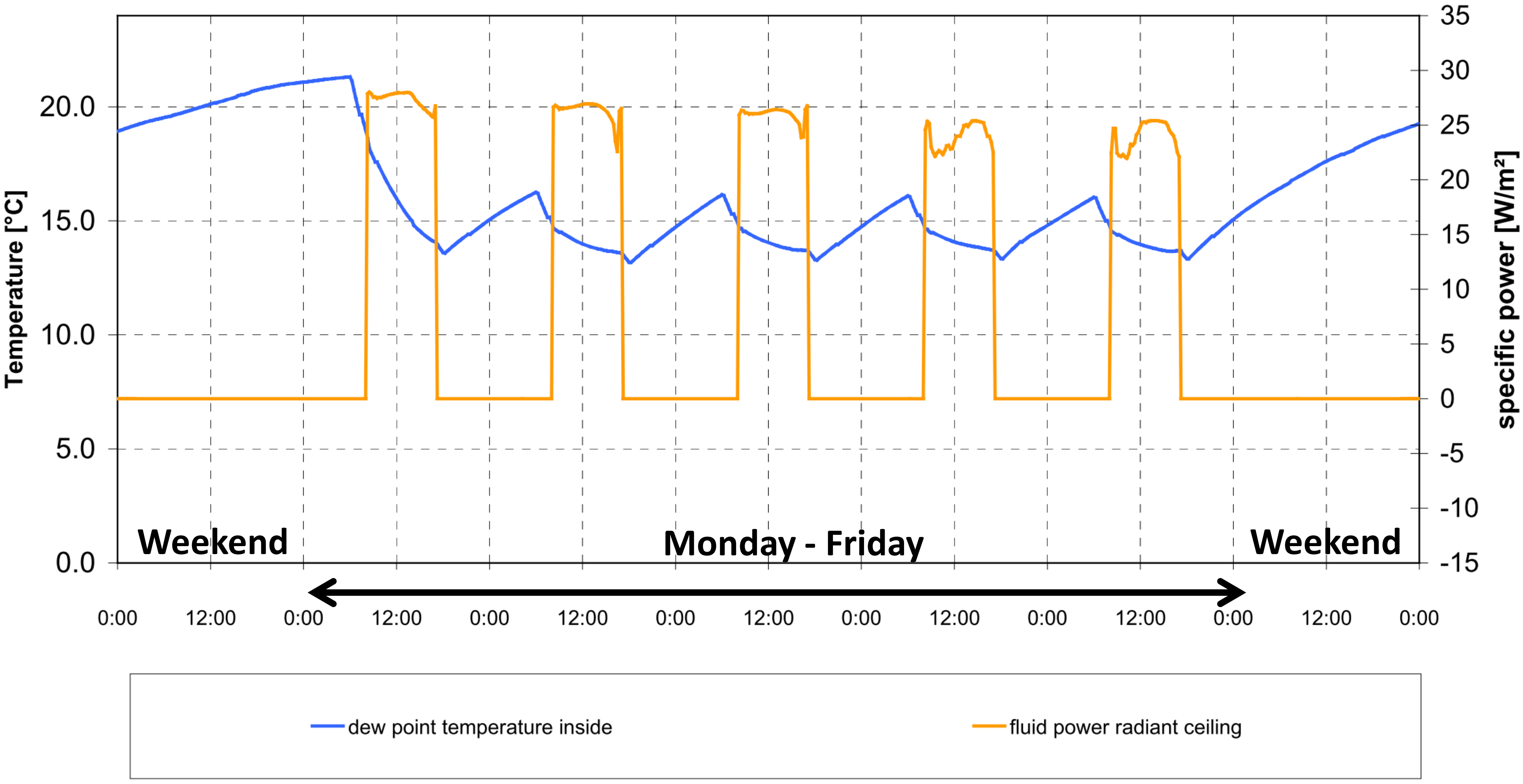
GEO Building

Computer modeling of GEO Building
by Transsolar using TRNSYS



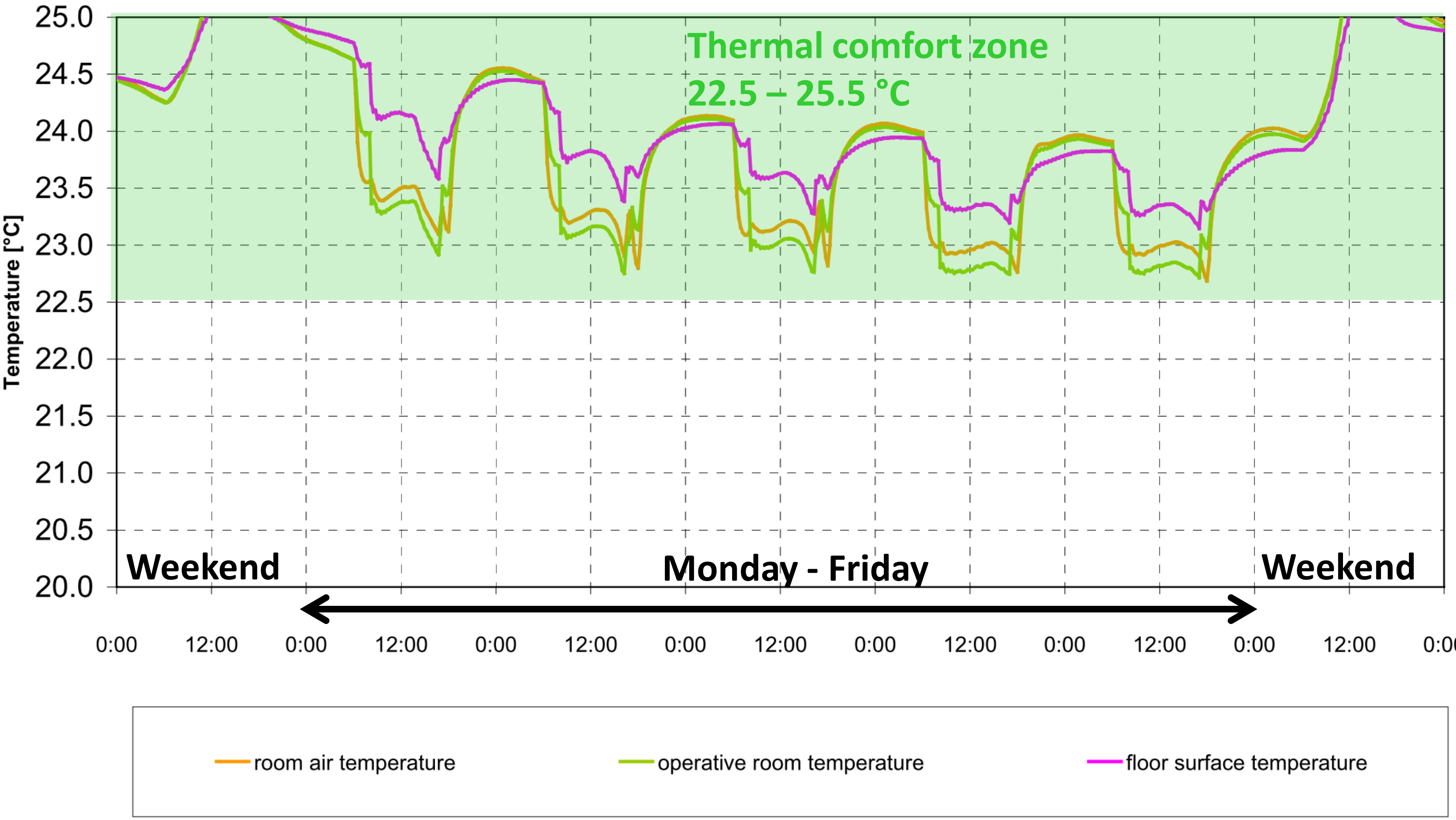
Energy Model for Metal Ceiling Cooling

Day time operation



Thermal Comfort for Metal Ceiling Cooling

Day time operation



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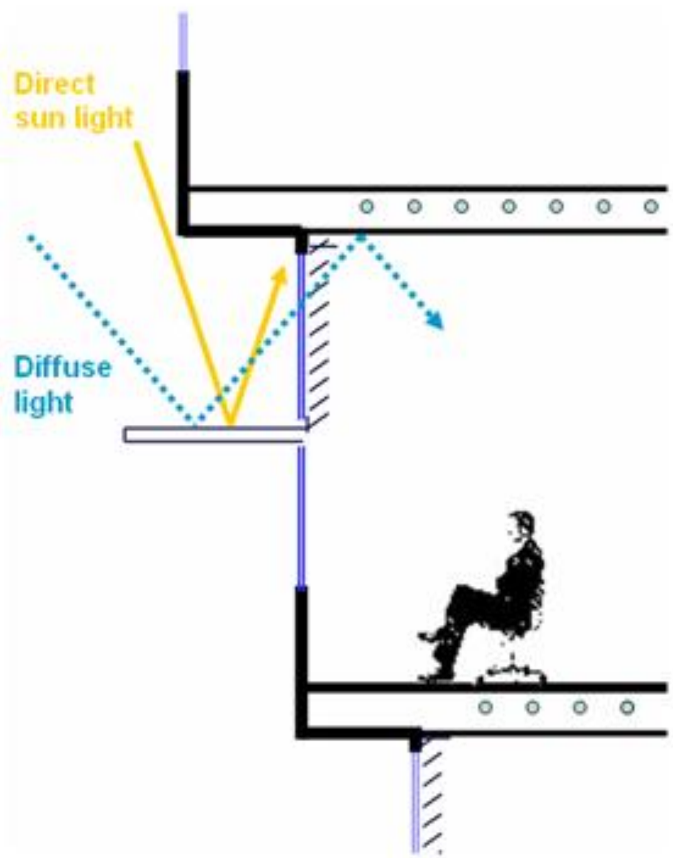
Simulated & Measured Energy for GEO Building

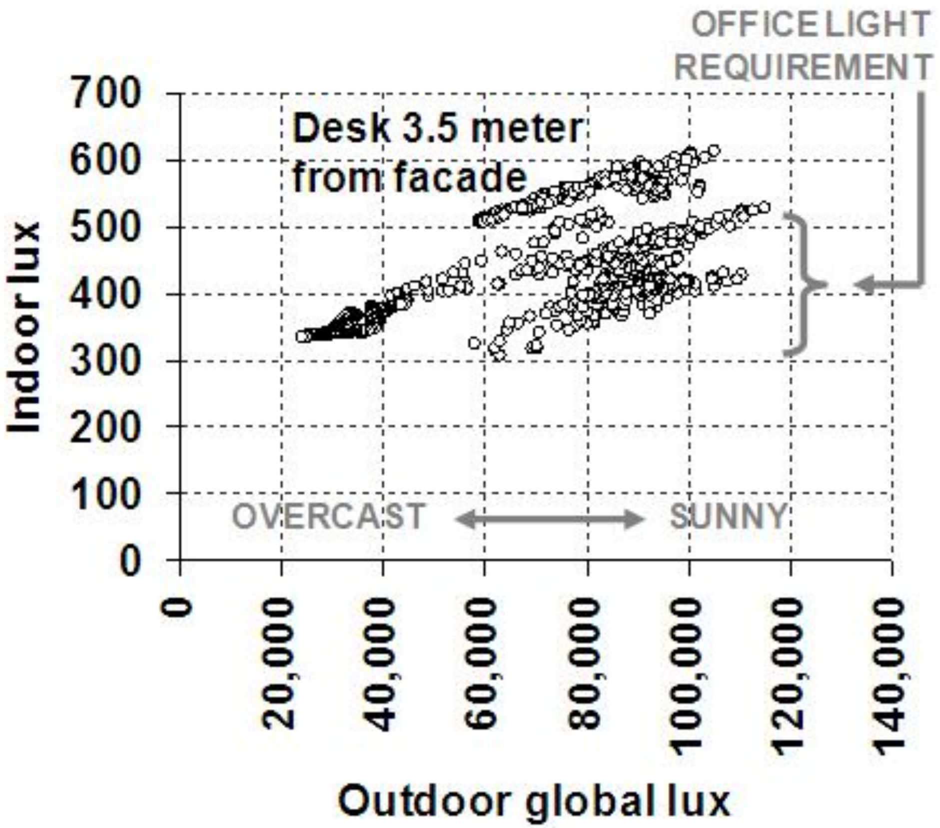
Good correlation

Annual (MWh/yr)	Simulated (MWh/yr	Measured (MWh/yr)	Data Logging Period	Remarks
Total Building Load		**268.93**	**2 weeks**	
Total Chiller Load	293.1	219.98	2 weeks	
COSP	6.2			
Lighting + Plug Load + Fans	66.1	70.35		Estimated
Plug Load + Fans	42 + 10	54.00	2 weeks	Plug Load obtained from DPM Logged Data minus the Lighting data
Lighting	13	16.35	2 weeks	Lighting Data for G, 1, 2 and 3 Fl
Lift		2.2	3 months	48% of energy goes to standby consumption
Chiller System	47.3			Logged Data
Chiller Power		175	2 weeks	
AHU Power		60	2 weeks	
PCM Tank Power		36	2 weeks	
Floor Slab (A+B)		0.1	2 weeks	

Split Window Design



Daylight Measurements



- Lighting consumption: 0.56 W/m^2
- Code requirement: 15 W/m^2

25 times more efficient

Transparent PV atrium roof

- PV sandwiched in low-e glass
- 13% transparent area

Daylight factor in atrium about 1 – 1.5%

Nice light pattern through PV atrium roof

Office case study in Bangi, Malaysia:

GEO BUILDING

Winner of 2012 ASEAN Energy Award

(ST Diamond Building, Putrajaya, Malaysia)

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Architects: Soontorn Boonyatikarn (Thailand) and NR Architect (Malaysia)
Energy efficiency and sustainability: IEN Consultants

Mechanical & Electrical: Primetech Engineers
Contractor: Putra Perdana Construction
Client: Malaysian Energy Commission

ASHRAE Technology Award 2013 (2nd place)

(ST Diamond Building, Putrajaya, Malaysia)

I | E | N CONSULTANTS

Architects: Soontorn Boonyatikarn (Thailand) and NR Architect (Malaysia)
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ST Diamond juxtaposed with Sarawak Longhouse

(in the book “The Cooperation”, 2012)

Examples and Initiatives

Malaysia and Denmark's, commitment to the field of

Green Energy in Architecture

as well as in cooperation and capacity building within the field, can be illustrated by the mutually beneficial involvement of IEN Consultants with the development of this field in Malaysia over the years. IEN Consultants was originally a proprietorship established by a Danish Chief Technical Advisor involved in the identification of energy projects in Malaysia. When the company took on the LEO Building projects it gained recognition in Malaysia and IEN Consultants managed to build up a team of consultants, most of them Malaysian, who with their experience on the LEO Building, became known further afield. This helped gain further commissions on such projects as the Green Tech Building and what has become known as The Diamond Building in Putrajaya.

“Green Buildings” are perceived to be expensive, both because of the costs of employing the expertise necessary to develop and refine the building and system designs, and because of the relatively high capital costs of green technology items. It takes time for reduced operating costs, which come with reduced energy usage, to counterbalance the increased capital investment and this has been a significant brake on development worldwide. However, given that approximately 40% of worldwide carbon emissions come from buildings, it is clear that the there is a need for the “greening” of buildings to make a significant contribution to carbon reductions.

As a result much effort has gone into the dissemination of green ideas to the Malaysian building industry, including the idea that the advantages of reduction of whole life costs of buildings as opposed to just capital costs are worthwhile. The fact that some “green” input to building design in Malaysia has moved from a subsidised base, using for example Danish funding for the LEO Building and European Union funding for the Green tech Office Building, to a fully Malaysia funded base in the case of the so-called “Diamond Building” indicates some success in changing attitudes to operating costs vs capital costs ascribed to “Green Buildings”.

Improved energy efficiency is already recognised by the Malaysian government to be more important than mere certification under the Green Building Index (GBI) scheme. That scheme therefore carries tax and stamp duty benefits to encourage the real application of green ideas in the design and operation of buildings.

Beyond this, IEN Consultants is now involved with a UNDP funded project, with the Ministry of Works, to promote low carbon buildings in Malaysia. It is hoped, amongst other things that it will lead to a building code by 2015 specifying much lower carbon footprints even than the LEO Building or the Diamond Building.

Modern sunshade
Diamond Building in festive season lighting

Traditional sunshade
Rungus Longhouse, Sabah

Another major area of involvement was in

Capacity Building for Malaysian Industry and Academia in EE Building design.

The objective of the scheme, which was implemented by the Ministry of Energy, Communications and Multimedia (now Ministry of Energy, Green Technology and Water), was to develop capacity in the optimisation of energy efficient building design. This was done through training sessions, seminars, specific analysis of existing buildings and design development of new buildings. A key partner in this endeavour was the Public Works Department (JKR) and there was close cooperation with Schools Division and Healthcare Division, so the lessons learned were comprehensive, and the dissemination of the results widespread.

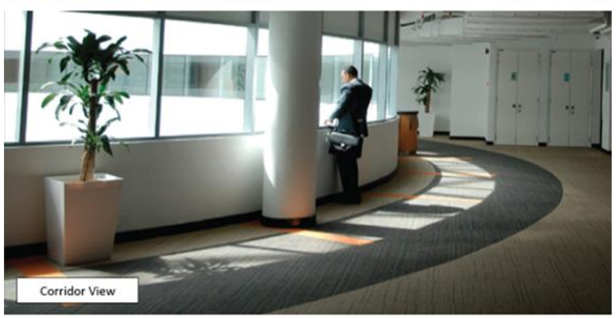
The project produced reports outlining design strategies for new buildings, making lessons learned from the LEO Building described above available to practitioners and academics across Malaysia. The project also produced reports on “Energy Efficiency Promotion: Lessons Learned and Future Activities”, and undertook an evaluation of JKR design standards.

The project certainly raised awareness and improved the country's knowledge base regarding energy efficiency in buildings and made recommendations to Ministry of Energy, Green Technology and Water and JKR to set up demonstration offices, a very successful example of which was in Wisma Damansara.

Examples and Initiatives

Book available free online:
http://um.dk/da/~/media/Malaysia/Documents/Other/Book%20Finalist%20LR.ashx

1/3 Energy Consumption
(ST Diamond Building)



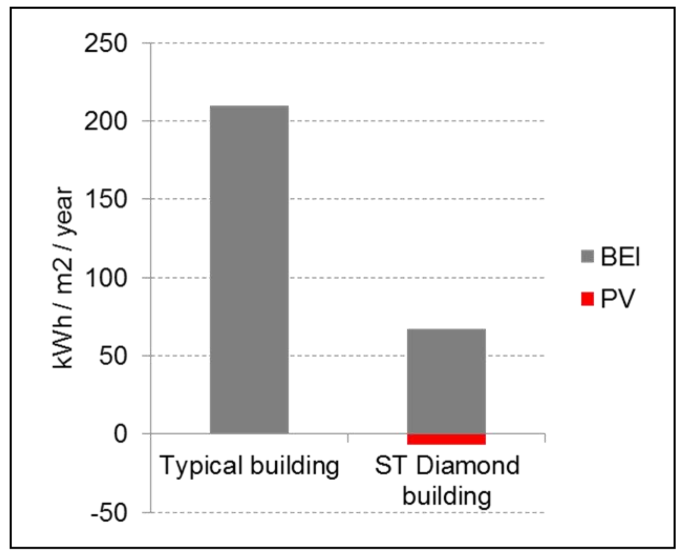
Key Data

Gross Floor Are: 14,000sqm
Year of Completion: 2010
Building Energy Intensity: 69kWh/m2*year
Total Construction Cost: RM60mil
Additional EE Cost: 3.2%
Payback Period: **< 3years**
IRR: 34% (based on 7year Lease Term)

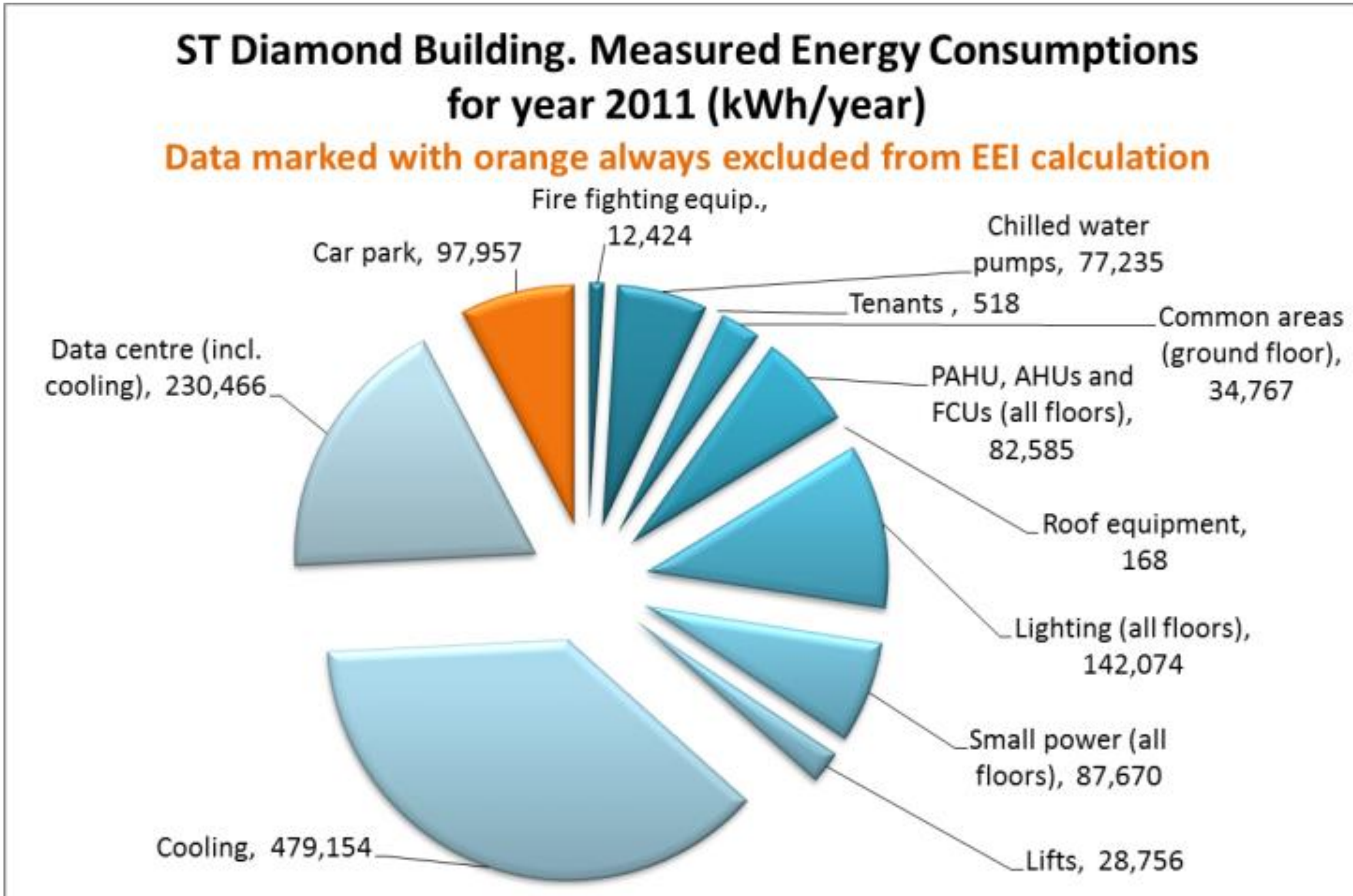
GBI **Platinum**

Green Mark **Platinum**

2012 ASEAN energy award **Winner**



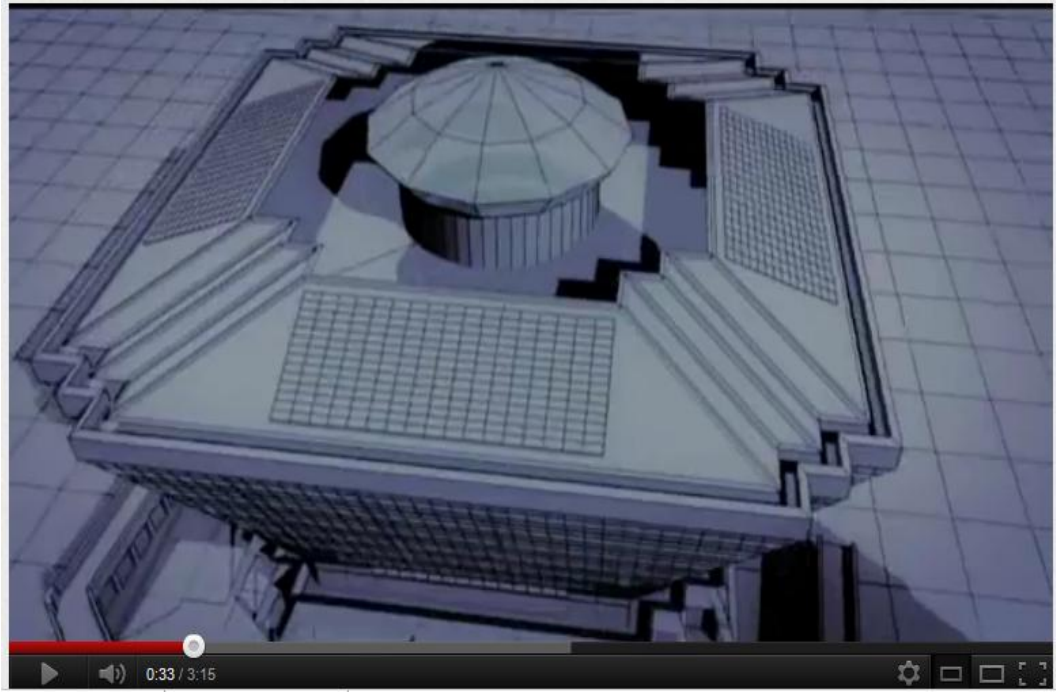
Measured Energy Break-down



Note:

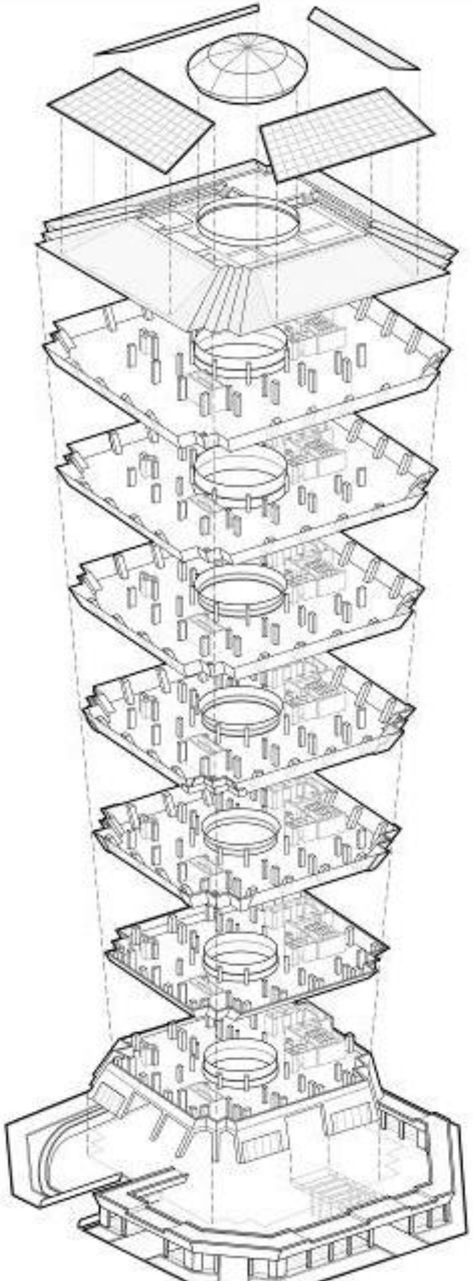
- District cooling has been converted to electricity using SCOP of 3.8

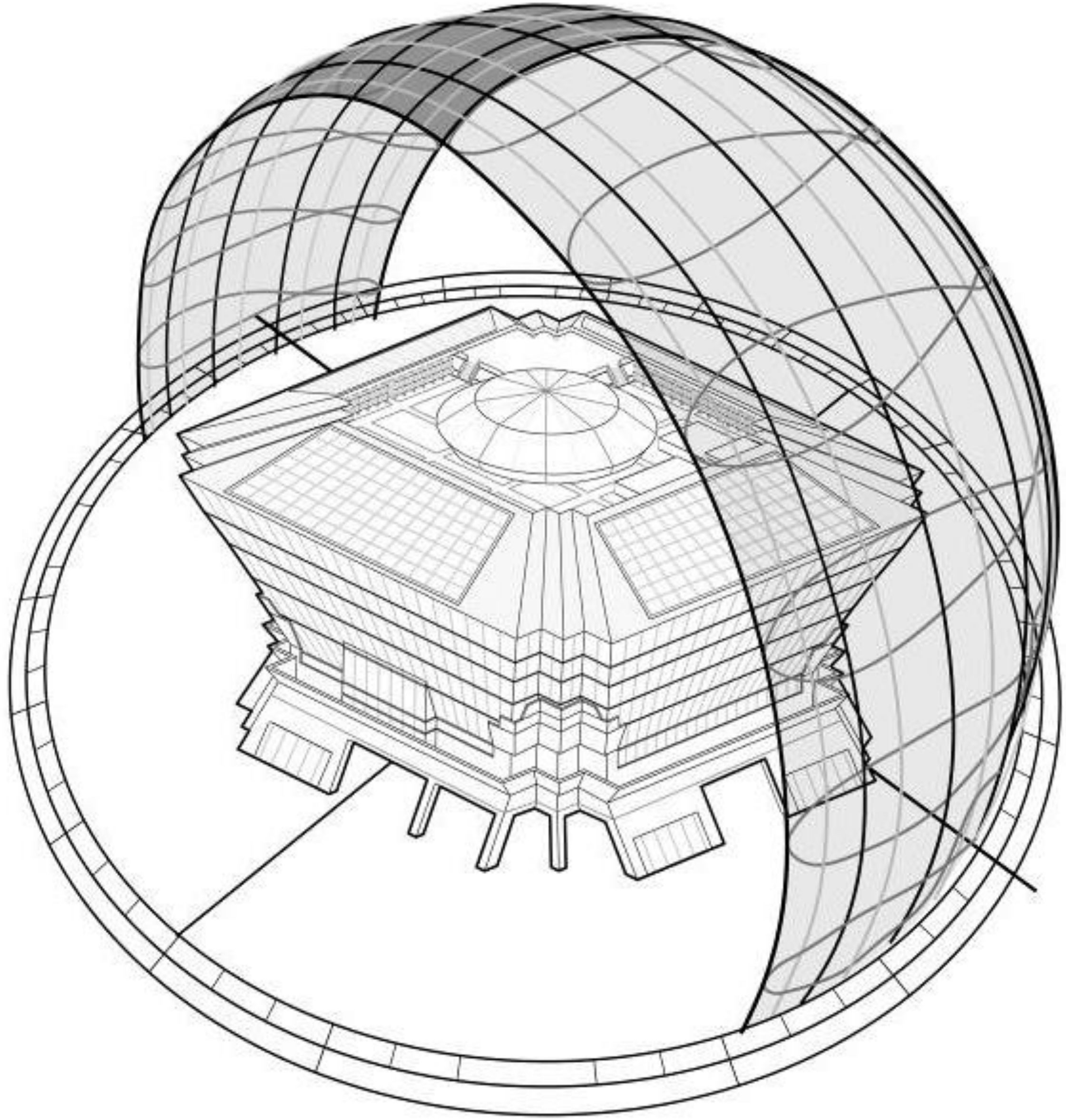
3-minute video



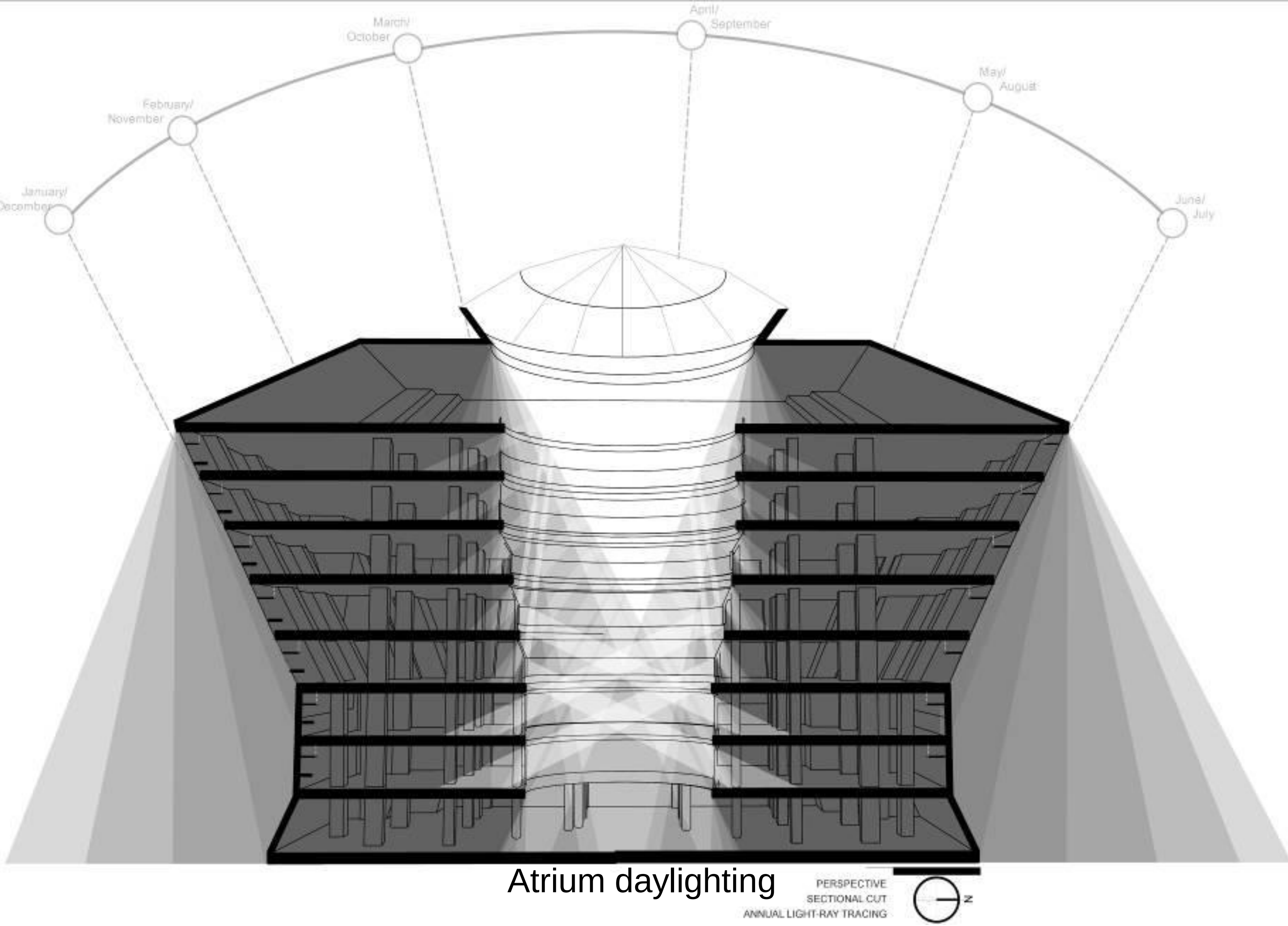
Sustainable Features of ST Diamond Building. Available at YouTube:

http://www.youtube.com/watch?v=3H_sXCtDayc



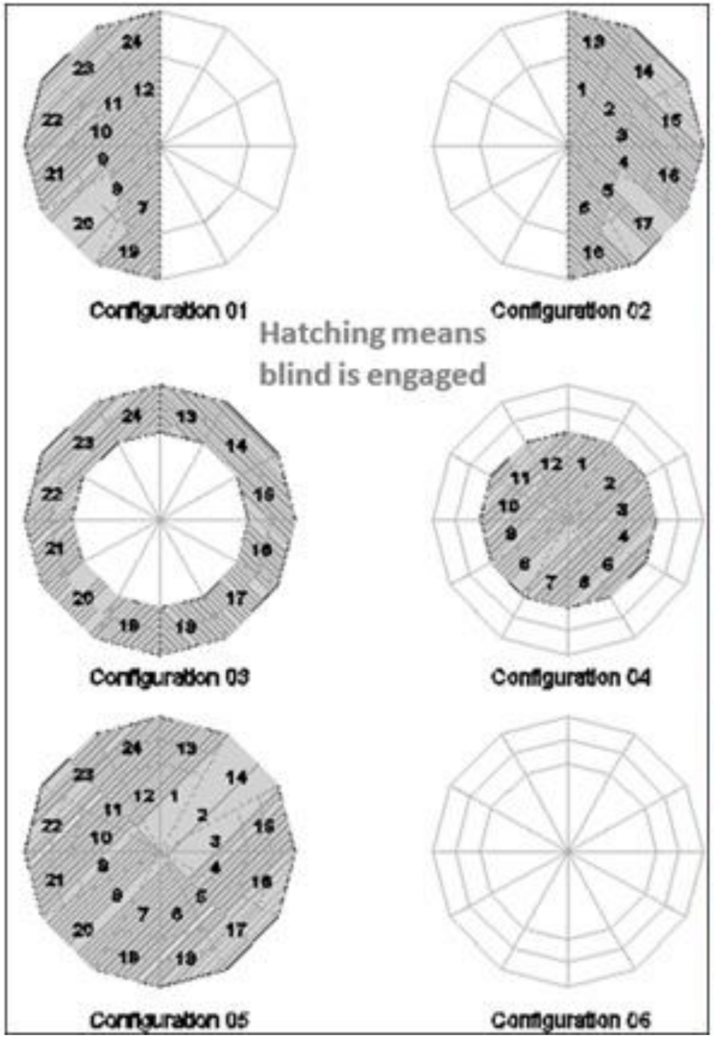


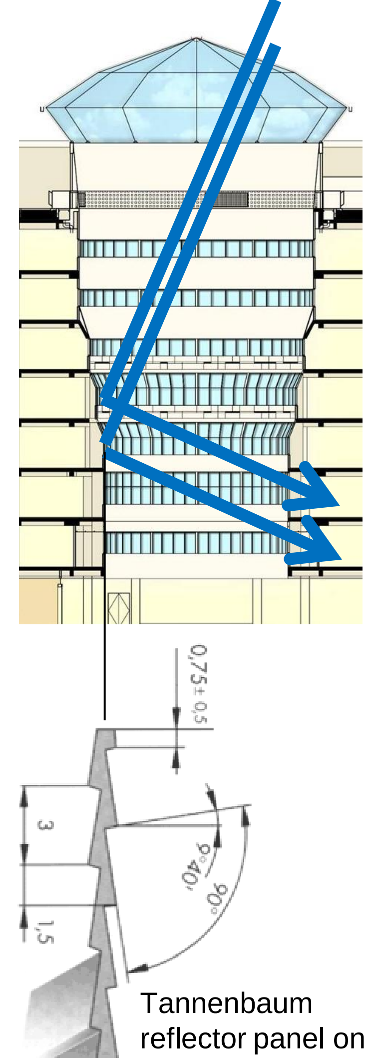
Self-shading facades



Atrium daylighting

Source: Greening Asia – Emerging Principles for Sustainable Architecture. Copyright: Nirmal Kishnani, 2012. Publisher: FuturArc

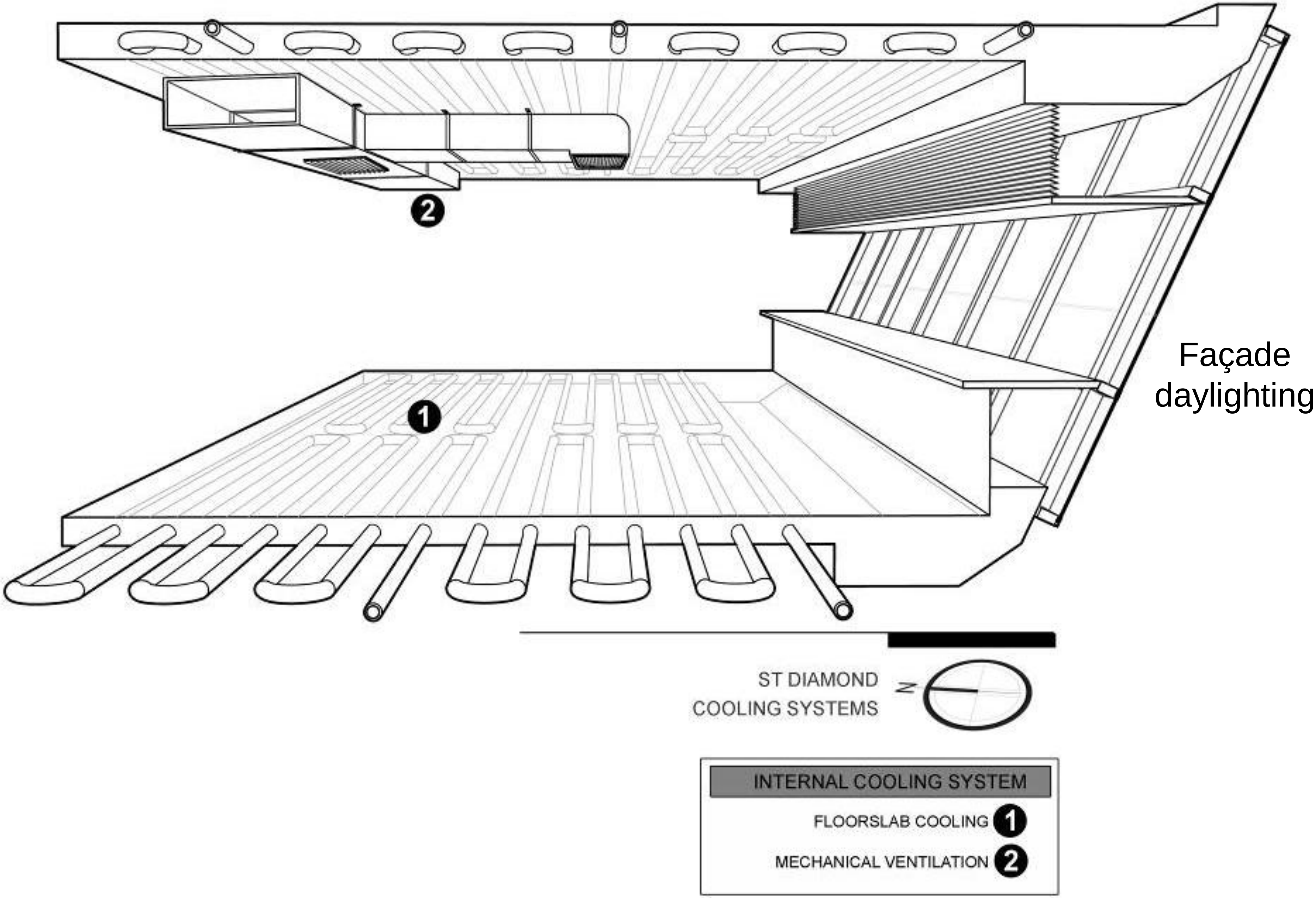




Atrium Daylight Design

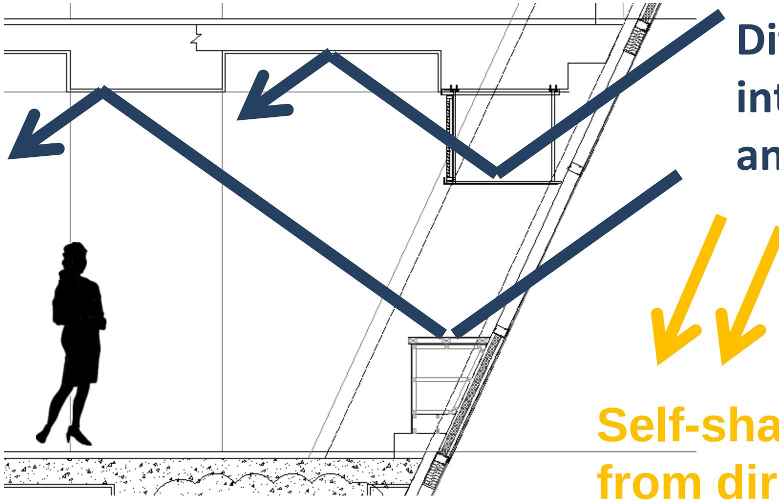
The atrium has been carefully designed optimize daylight utilization for each floor employing the combination of the following three strategies:

1. Automated blind with six different configuration to maintain the appropriate daylighting levels at all times. The blinds with 30% light transmittance are adjusted every 15 minutes and follow a three different control strategies for morning, mid-day and evening
2. The windows size becomes larger deeper into the atrium to cater for lower daylight levels
3. A band of Tannenbaum reflector panels are applied to 4th and 5th floor to deflect daylight across the atrium to 1st and 2nd floor where daylight levels are the lowest. The 'christmas tree' profile reflectors have an inclination of 10° and reflect about 85% of the light in semi-diffuse manner, hence, avoiding visual glare issues for the building occupants.



Source: Greening Asia – Emerging Principles for Sustainable Architecture.

FACADE

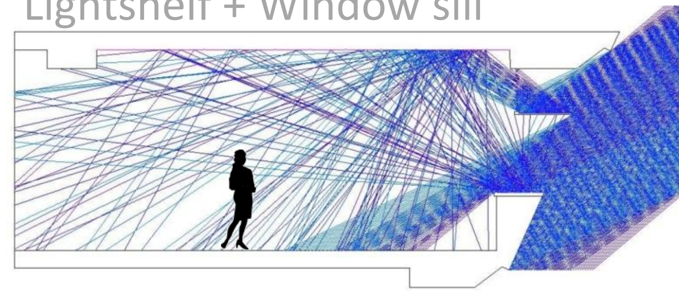


Diffuse light deflected into room by lightshelf and window sill

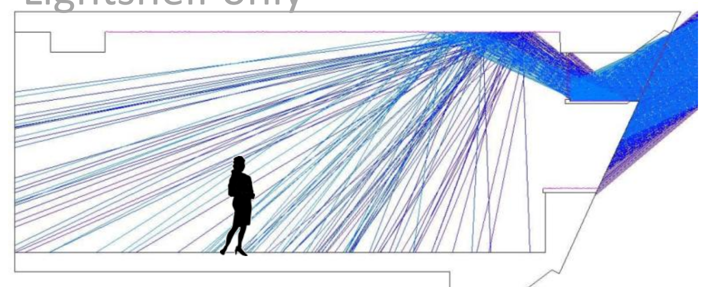
Self-shaded facade from direct sun

LIGHT REFLECTIONS FROM:

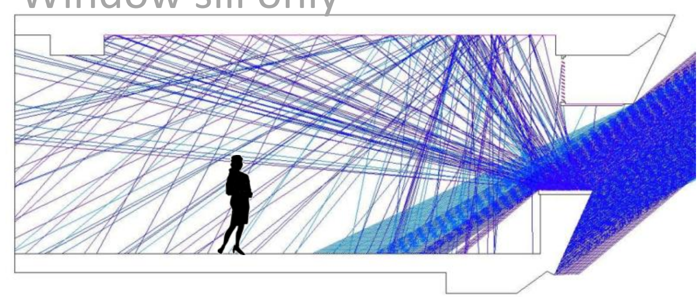
Lightshelf + Window sill



Lightshelf only



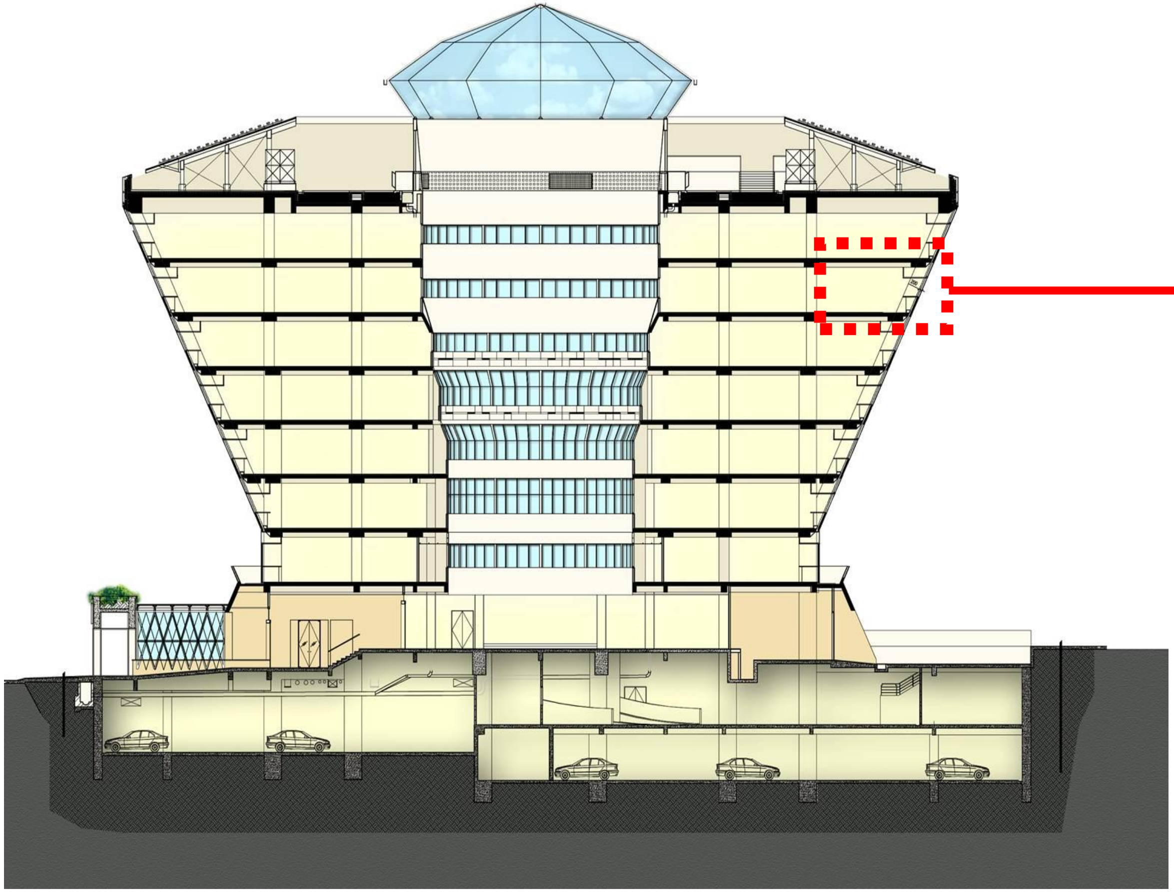
Window sill only



Façade Daylight Design

The building is 50% daylit. The façade daylighting system consists of a mirror lightshelf and a white painted window sill. Both deflect daylight onto the white ceiling for improved daylight distribution until 5 meters from the façade + 2 additional meters of corridor space. Installed office lighting is 8.4 W/m2, but 1-year measurements show consumption of only 0.9 W/m2 showing high reliance on daylighting

Day-Lighting- Office



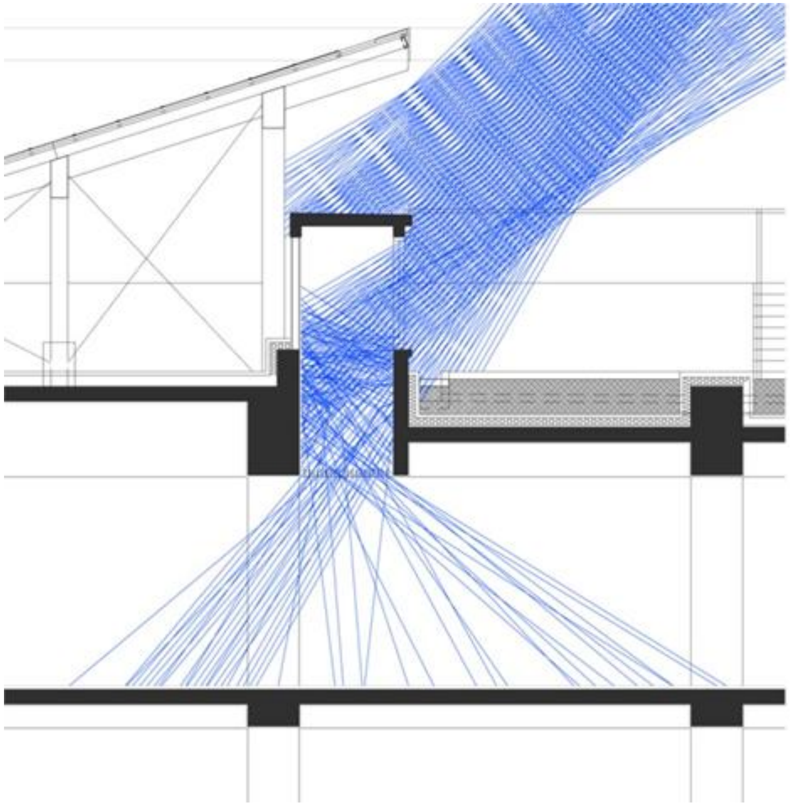
Mirror lightshelf

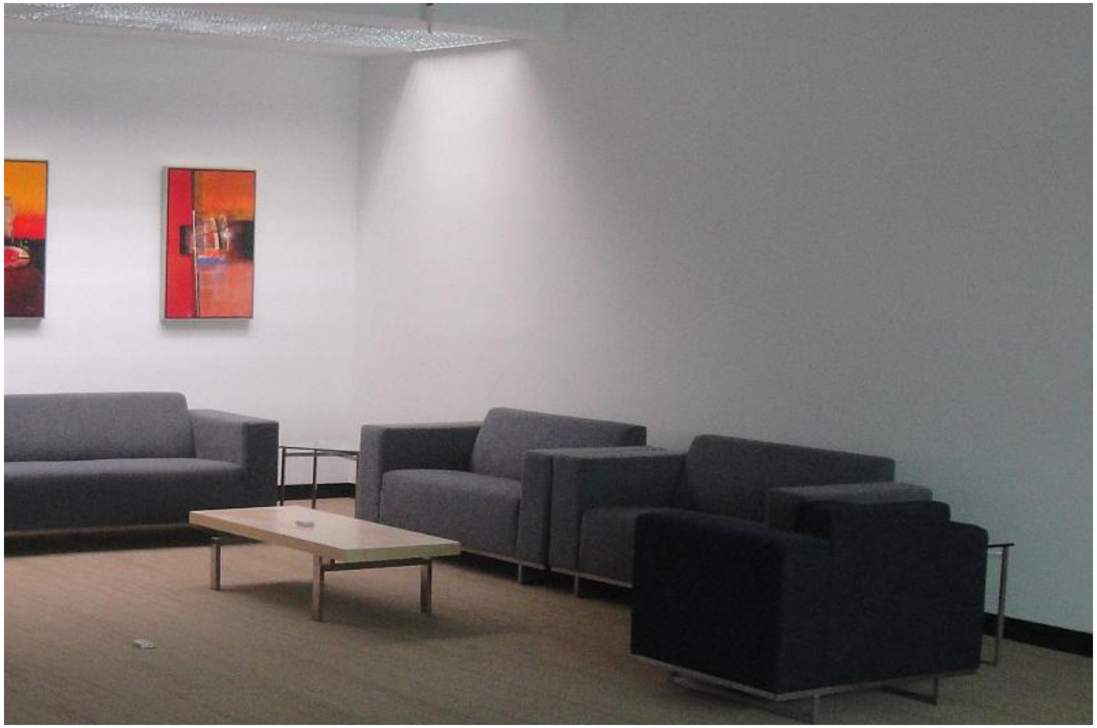
Fixed blinds for glare control

Daylight reflected onto ceiling

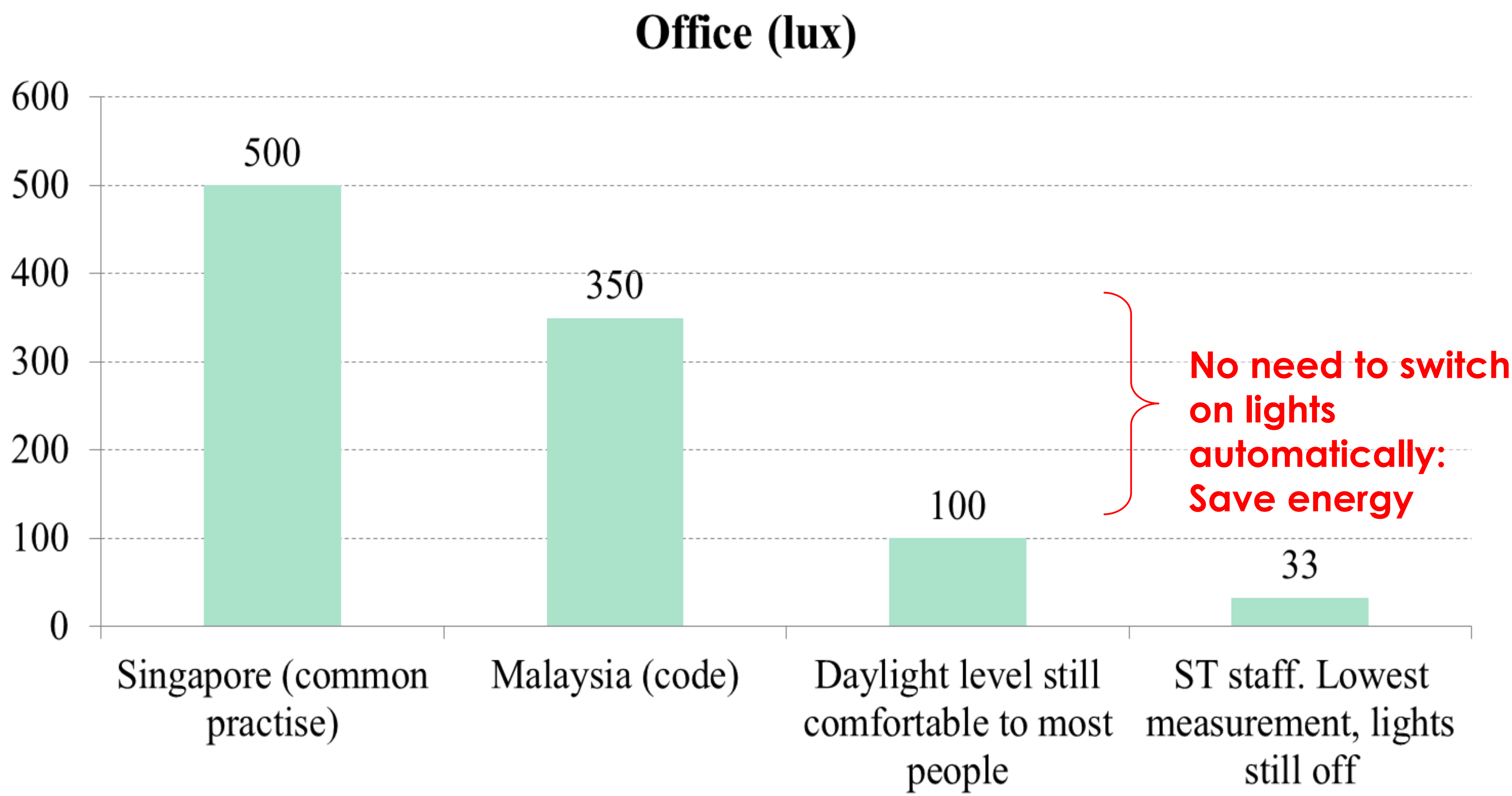
Daylight Skylight through Roof

Take in diffuse light only





Lighting Levels



Floor Slab Cooling in ST Diamond Building

Floor slab cooling system embedded in RC slab

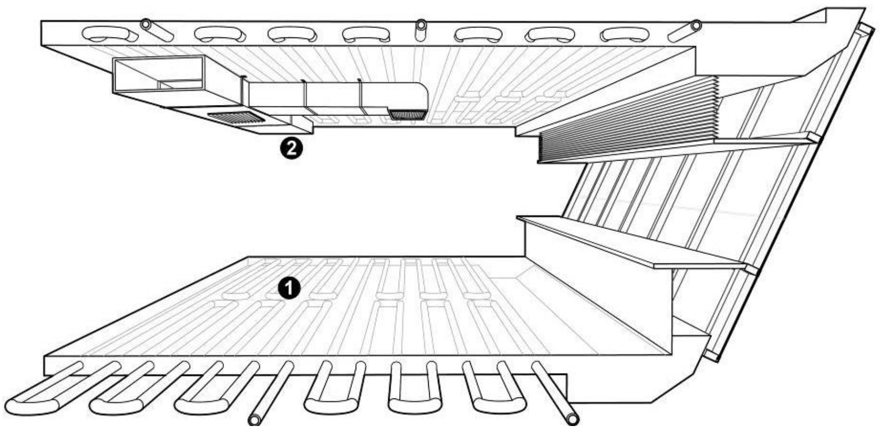
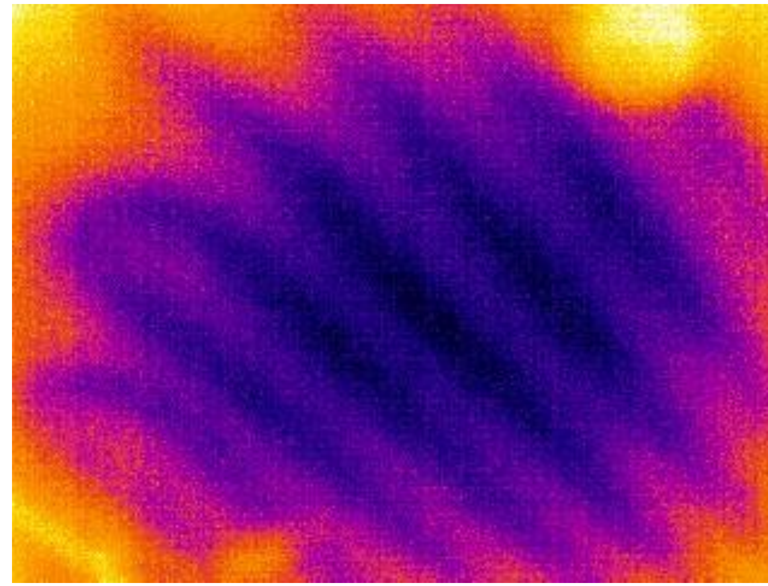
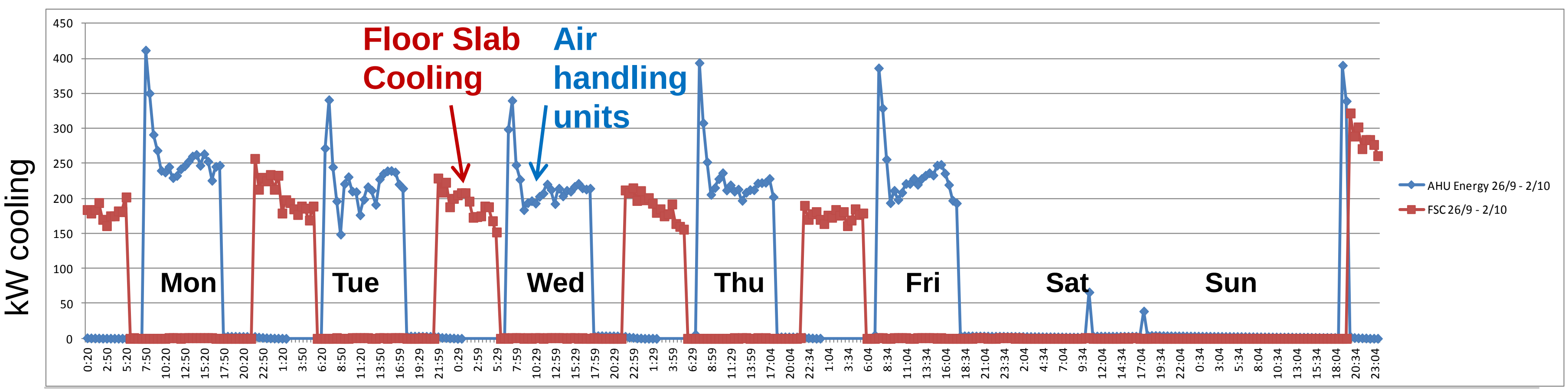


Illustration courtesy of:
Greening Asia – Emerging Principles for Sustainable Architecture.
Copyright: Nirmal Kishnani, 2012. Publisher: FuturArc



Thermographic image of floor slab cooling in ST Diamond
Picture courtesy of: PS Soong, Pureaire



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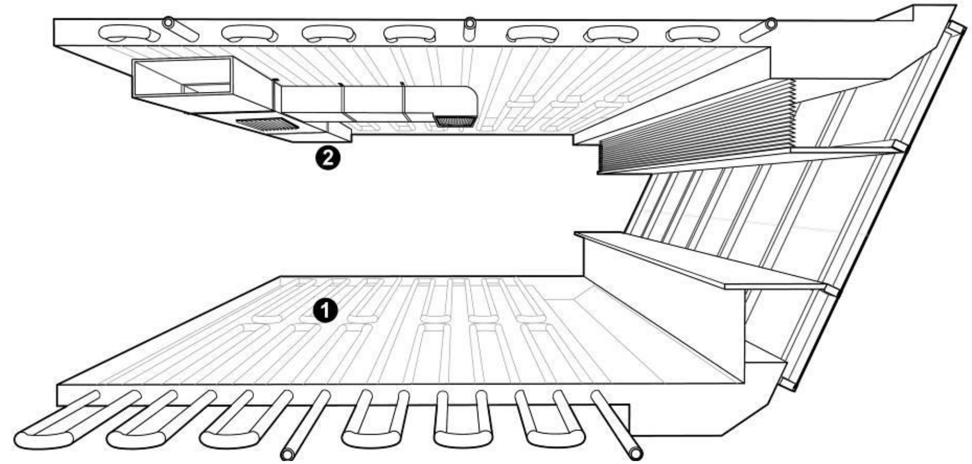
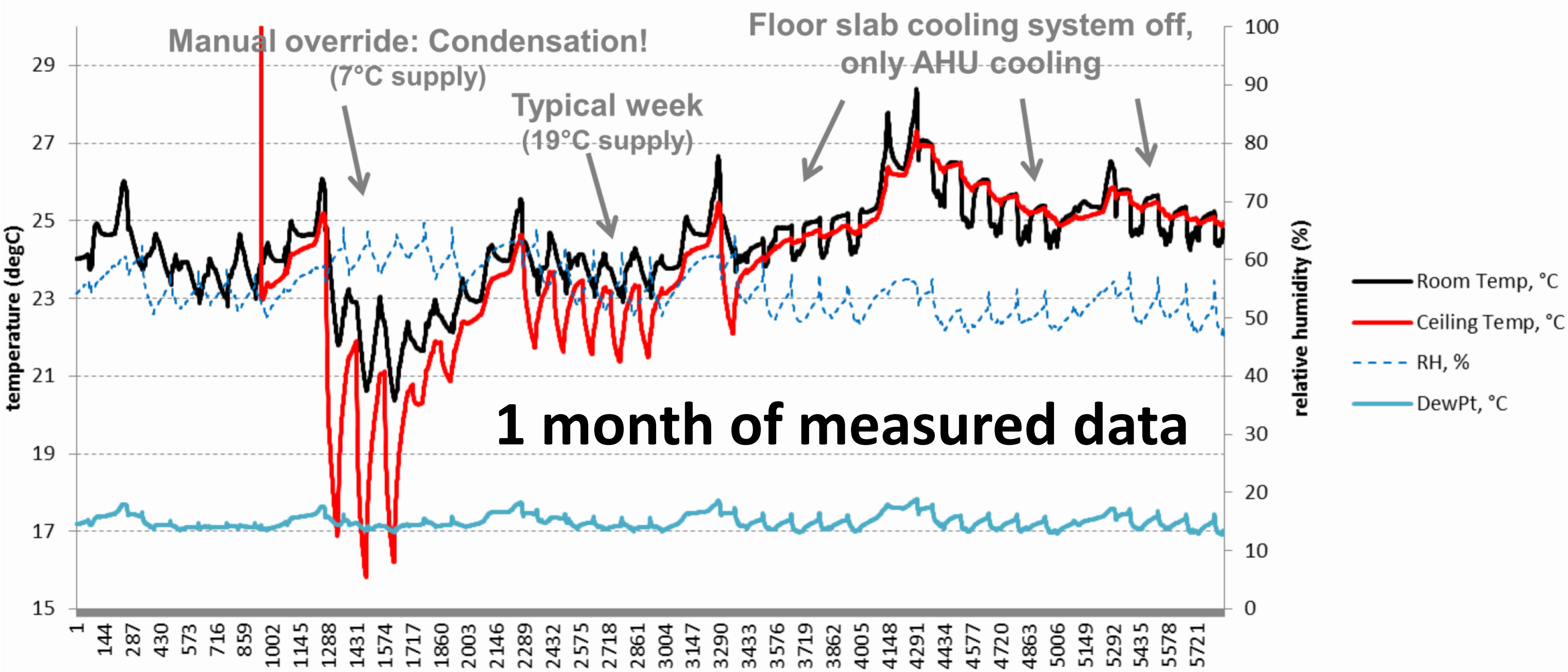
ST Diamond Building: Floor slab cooling measurements



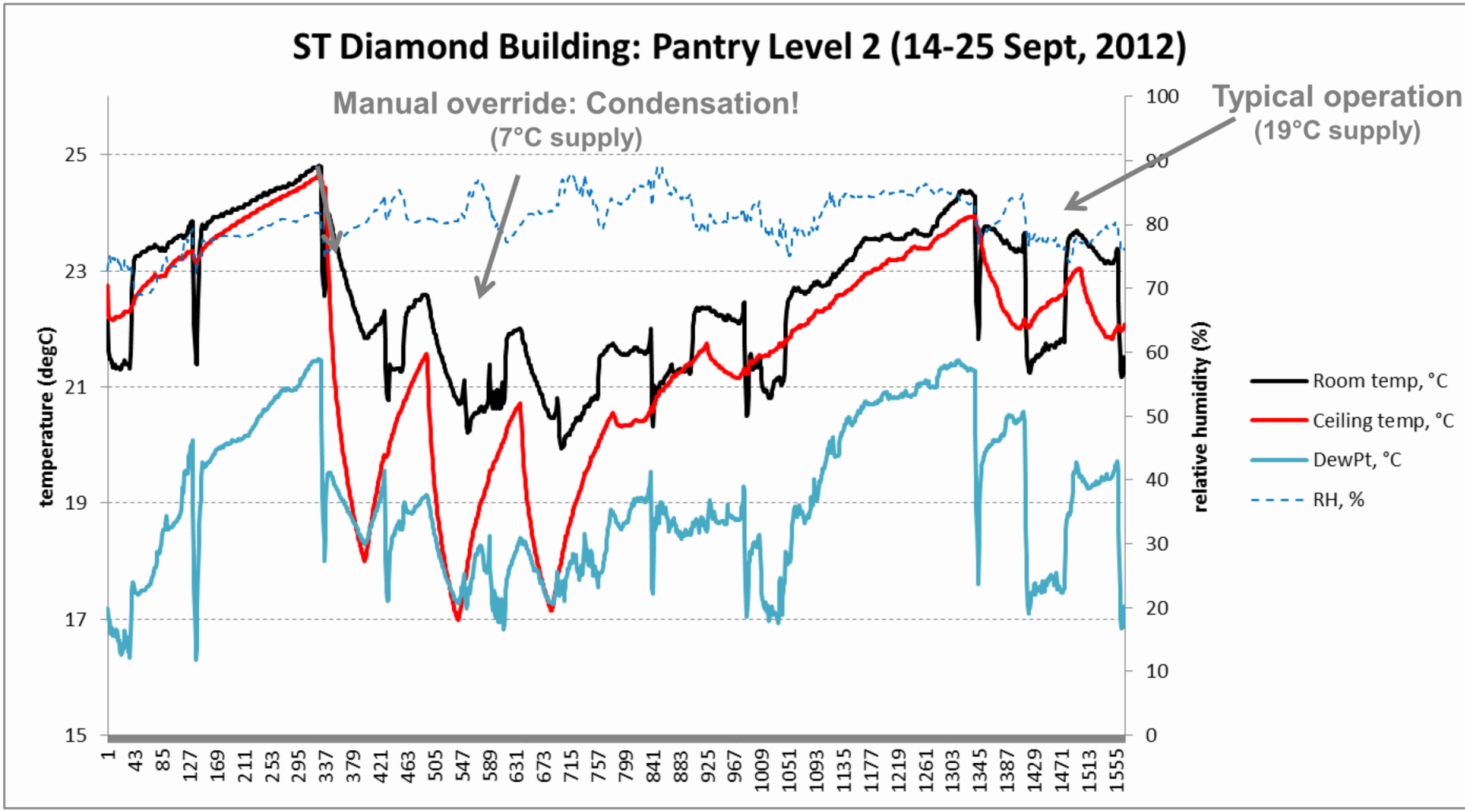
Source: Greening Asia – Emerging Principles for Sustainable Architecture.

ST Diamond Building: Level 6, West, Hamidah room (8 Sept - 18 Oct, 2012)



Floor Slab Cooling: Condensation accident!

Due to manual override of supply temperature to floor slabs



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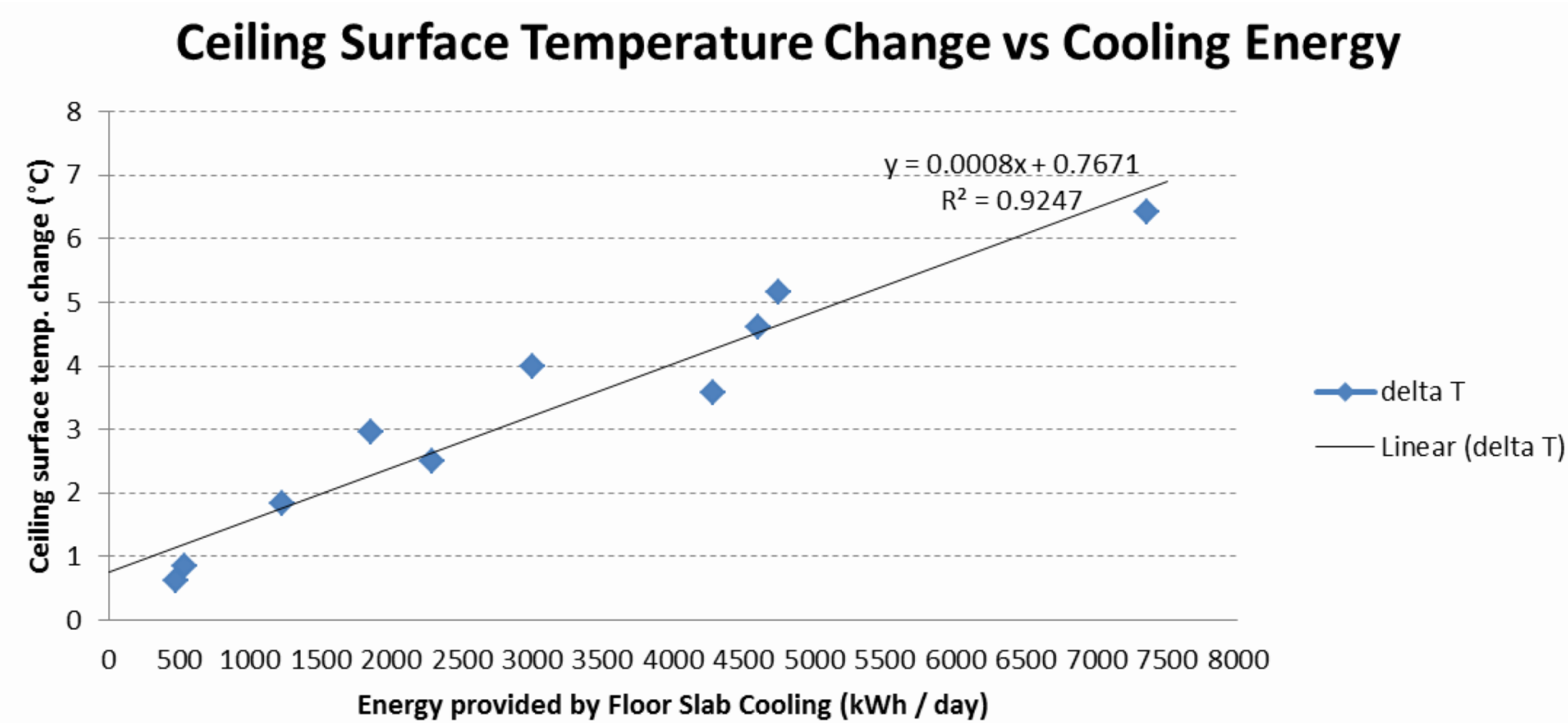
Floor Slab Cooling: Measured Correlation

Clear correlation between ceiling surface temperature and Cooling energy



Final slide: Lessons from Radiant Cooling

1. Radiant cooling can save energy
   - higher COP
   - lower transport energy
   - off-peak cooling

2. Indoor air velocity must not drop, or people will feel uncomfortable from 'stuffy air' or 'lack of air movement'

3. Condensation is a challenge that can be overcome if design and building usage is correct

Thank you

I will be happy to email you the presentation

Gregers Reimann

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